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"Integrated Nutrient Management on Farmers' Fields: Approaches that Work"

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The Soil Fertility Workshop at Reading

Preface

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Background

The Department for International Development or DFID (formerly the ODA) uses the aid programme to finance technology development and research (TDR) in a number of fields judged to be important for resolving problems currently facing many developing countries. The emphasis of these TDR programmes is increasingly on applied research, and the transfer and adaptation of technology to the circumstances of each country, with the objective of eliminating poverty.

DFID's Renewable Natural Resources Research Strategy (RNRRS) from 1995 to 2005 includes five strategy areas, which cover research programmes on agriculture, forestry, livestock, fisheries and natural resources systems. In all these fields, DFID seeks to achieve uptake of research results and impact on livelihoods by supporting systems-based research projects that adopt participatory approaches for identifying farmers needs and systems constraints.

The last of these programmes, the Natural Resources Systems Programme (NRSP), convened a workshop on the theme "Integrated nutrient management on farmers' fields". This is a research area in which the United Kingdom considers it has a comparative advantage and can make a contribution to the international efforts aimed at improving soil, water and nutrient management in developing countries.

The workshop was held at the Department of Soil Science, University of Reading, UK from 14 to 16 September 1997, and was arranged and run jointly by the Soils Department of the University of Reading and by research managers for five of the seven Production Systems into which the NRSP is divided.

Sixty participants were invited from the main UK institutions concerned with soil fertility, and from international research centres and programmes, including CIMMYT, CIAT, TSBF, IBSRAM, and RWCIGP (the Rice Wheat Consortium of the Indo-Gangetic Plain), and senior staff from national institutions in some of the NRSP target countries, including India, Bangladesh and Ghana. Participants were asked to stand back from their own institutional and disciplinary affiliations and help the organisers to identify how and where the available research funds could be deployed to greatest effect in each of the Production Systems represented at the workshop.

Objectives

The Objectives of the workshop were:

1. to summarise ongoing programmes, knowledge gaps and research opportunities,
2. to define a soil fertility/INM research agenda for NRSP over the next 7-8 years,
3. to identify and prioritise fundable systems-based projects.

The workshop and the subsequent projects focus on farmers, their problems and perceptions, and on research that will contribute directly to the elimination of poverty. This means good science must be combined with participatory activity to achieve sustainable impact. The challenge will be to combine scientific rigour with developmental uptake on farmers' fields.

Structure

The detailed programme for the workshop is included elsewhere in this report. After a short introduction to the Natural Resources Systems Programme, the structure of the workshop was explained. A number of cross-cutting papers were presented that described ongoing related research activities in other national and international programmes, including the CG centres, to outline a global context for the proposed NRSP research projects and to identify the UK comparative advantage. Three papers were then presented which sought to provide a farmer perspective on adoption of improved technologies, and particularly on the role of organic materials.

The meeting then divided into working groups based on the five NRSP Production Systems represented at the workshop. For each, keynote papers were distributed to participants before the workshop; these were summarised at the start of the working group session, and responses invited, before opening each session for more general debate. The groups were each asked to report their outputs back to the plenary sessions as a summary of the discussion, the principal researchable constraints and priority issues, and a shortlist of three priority projects for each Production System.

To start the second day, several regional papers were presented to focus on the variety of environments and typical issues in each, before listening to the presentations from the working groups. These were followed by an overview of the issues and researchable constraints gleaned from a range of review documents already available to management from within and outside the RNRRS programmes. The final plenary session considered the general balance and coverage of the working group reports, noting in particular the cross-cutting themes that might be tackled together.

A number of resource materials were distributed to participants during the workshop, and an impressive selection of 18 posters were on display.

Conclusions

On the workshop

The working group format was determined by the division of the NRSP - and the other programmes of the RNRRS - into what have been termed Production Systems; these roughly correspond to widely recognised agro-ecological zones. Each is dominated by a central group of themes and issues, deriving from its peculiar physical or socio-economic characteristics, though with some theme areas that overlap with adjacent zones. As a structure, this seemed to work because it allowed debate to concentrate on the specific Production System without excluding the more generic and cross-cutting issues.

On the Production Systems

The detailed reports are available for each of the Production Systems and they broadly follow the requested format of researchable constraints, priority issues and a shortlist of suggested projects. Though not all groups achieved a consensus on specific projects, all could define the research themes of greatest importance and interest.

The main research areas extracted from the detailed accounts are summarised below.

Semi-arid

1. The limited physical availability of organic materials means that sustainability of semi-arid systems depends on optimising the use of whatever is available, and on finding ways to increase the overall supply of organic materials.
2. Nutrients are in short supply, and inefficiently used; with this narrow safety margin, the determinants of nutrient use efficiency at farm level must be understood to make them sustainable.

3. Already scarce nutrients are transferred off-farm in crops and livestock, so that better understanding and management of nutrient flows is needed to improve rural livelihoods.

Forest-agriculture interface

1. Forest clearance and burning directly reduce soil fertility; sustainability therefore requires the development of appropriate cropping patterns and organic residue management to ensure availability and use of nutrients.
2. Soil organic matter is reduced by forest clearance, and unsustainable agricultural practices degrade land further: the critical levels to maintain SOM functions must therefore be defined before sustainable organic residue management regimes can be devised.
3. Generalised soil research outputs are not accessible to farmers in a form that farmers can readily use to make niche-specific decisions and this interface needs more attention.

Peri-urban interface

1. At the city or regional level, management of urban wastes should involve an evaluation of them as sources of organic or inorganic nutrients for agricultural production as well as the environmental or pollution impact of the various management options.
2. Peri-urban farmers have greater opportunities to benefit from urban-based nutrient sources than their rural counterparts, but they face greater complexity, and need decision trees or choice pathways which cover a wide range of options for sustainable nutrient management and pathogen control, and greater knowledge of long and short term nutrient release and interactions.
3. Environmental sustainability requires research to achieve optimum production while avoiding or controlling pollution from organic and inorganic sources within very specific agro-ecological and cultural situations that will probably be unique in each city region.

Hillsides

1. Combatting nutrient losses: address undesirable soil nutrient flows due to leaching and erosion by devising, testing, modifying and adapting a range of interventions presented as feasible farmers options.
2. Reversing soil organic matter decline by improving farmers' management and use of existing and alternative sources of organic matter inputs.
3. Improving water management for both surplus and deficit conditions by devising, testing, modifying and adapting with farmers a range of interventions and options.

In each case, existing farmer knowledge should be the documented starting point and basis for interventions, requiring understanding of farmer decision-making and of his or her socio-economic context.

High Potential

1. Participatory research to identify and test appropriate methods to reverse declining productivity, and to improve efficiency of nitrogen use in the continuous rice cropping systems in Asia.
2. To develop, introduce and accelerate the adoption of new tillage and integrated nutrient management practices in the rice/wheat systems of the Indo-Gangetic Plain.
3. To identify and analyse improved management practices that combine the introduction of plant genotypes, soil and water conservation, and integrated nutrient management for the

rainfed uplands of eastern India.

4. To develop options for the combined use of organic and inorganic nutrient sources that take account of the circumstances of individual farmers on the rainfed uplands of Africa.

There is considerable overlap and complementarity in the research themes identified, leading to a number of cross-cutting themes which reflect similar problems in several Production Systems; these might become the subject of joint funding of research. There is a recognition that the problems are only in part to be solved by technical innovation from the researcher; the compelling need to involve farmers in the identification of both the problems and the solutions is accompanied by an awareness that impact is dependent on a realistic assessment of the farmers' flexibility to embrace change and of his or her decision-making processes.

The workshop has broadly fulfilled its stated objectives, and identified priority research projects or research themes. The next step is for NRSP management to relate these to the existing (or revised) logical frameworks for each Production System, and to consider how best to pursue the agenda that has been formulated by the workshop. This will be one theme for discussion at the next NRSP Programme Advisory Committee meeting on 13 and 14 November 1997; the concrete next steps will then be drawn up by each Production System Leader in consultation with the DFID Programme Manager.

DFID support for renewable natural resources research

Dr J. C. Barrett
Manager, Natural Resources Systems Programme

Importance of the natural resources sector for British aid

Between 20 to 25 per cent of total aid flows (all donors) to developing countries are directed towards the renewable natural resources sector. It provides livelihoods for some 75 per cent of the population in developing countries, and a major contribution to GDP and export earnings in many of the poorest countries. Providing obvious scope for projects designed to reduce rural poverty and to promote sustainable economic growth, the natural resources sector has always been an important focus of British aid.

The Department for International Development (DFID) has emphasised the importance of knowledge generation in support of its activities. This will be achieved through continued investment in research and research capacity in developing countries and through partnerships with the science community in the UK and internationally.

The Renewable Natural Resources Research Strategy

In addition to country-specific research projects funded under the bilateral programme and grants to international research centres, DFID also funds knowledge generation programmes managed from the UK across a wide range of fields judged to be important to resolving problems facing poor people in many developing countries.

Since 1989, the Renewable Natural Resources Research Strategy (RNRRS) has defined DFID priorities for strategic research on commodities and cross-cutting issues of regional importance. Discipline-based research programmes have been contracted out to managing institutions. The RNRRS was reviewed in detail in 1993/94 by a Research Task Group whose recommendations formed the basis for a major revision of the RNRRS, implemented with effect from April 1995, with the expectation of remaining in place for a ten year period.

The wider goals of the strategy remain to reduce poverty, promote economic growth and reform and to mitigate national environmental problems, while the specific purpose is to enhance the productive capacity of the RNR sector. There are important emphases in the revised RNRRS, designed to improve the quality, relevance, uptake and developmental impact of research supported by DFID.

Improved relevance

Research proposals must be "demand-led", responding to clearly defined problems of a specified group of beneficiaries. Such problems should be seen as a priority within the countries where research results are expected to be taken up. Collaborating institutions and intermediate users of the research results in those countries must also affirm their commitment to the importance of the proposed projects.

Research must be problem-oriented. There is a strong emphasis on the use of logical frameworks, at both the programme and project level, to improve both the design and management of activities. This helps to ensure that adequate attention is given to how the outputs of the research will be promoted to achieve uptake and developmental impact. The programme views this of such importance that we provide one-day training workshops on logical frameworks, free of charge, to applicants who submit successful concept notes.

Improved uptake and impact

RNRRS programme managers fund projects in a limited number of countries, according with wider DFID policy objectives. The reason for this geographic focus is that projects must take proper account of the institutional, social, cultural and policy environment in target countries if research results are to lead to developmental impact. This requires substantial investment in understanding the context, and developing effective partnerships with in-country collaborators.

The revised RNRRS adopts a production systems perspective, to provide a clearer context in which development constraints and opportunities are prioritised for research which will be supported by DFID. The production systems are: semi-arid; high potential; hillsides; tropical moist forest; and three interface zones - forest-agriculture, land-water and peri-urban. These production systems feature in all of the twelve new RNRRS programmes. This evolution is further emphasised in the establishment of the Natural Resources Systems Programme.

Improved research quality and cost-effectiveness

In general, the management contracts for RNRRS are now being awarded through competitive tendering. Project selection procedures are rigorous and competitive, with research proposals being evaluated by independent assessors. Programme Advisory Committees have been established for this purpose, which are made up of eminent experts across the field, who are independent of the managing institution.

The Natural Resources Systems Programme (NRSP)

Created in 1995 as a new programme within the revised RNRRS, the Natural Resources Systems Programme (NRSP) reflects a widely felt need for more integrated approaches to RNR management, and the need for a better understanding of the complex interactions and interrelationships affecting resource use. Emphasis is placed upon identifying the major systems constraints, and their resolution by integrated approaches.

In summary, the research priorities for the NRSP encompass:

Semi-arid:	water conservation, water use efficiency, and risk reduction through optimisation of land use, including maintenance of soil fertility.
High potential:	enhancement of productivity through appropriate balance of inputs and outputs; soil fertility.
Hillsides:	soil erosion; deforestation; soil fertility
Interface systems:	concern with land use planning, resource utilisation, and coping strategies.

In addition to six production system portfolios, there is a socio-economic methodologies component of the NRSP, designed to address methodological problems in the improved design, implementation, evaluation and uptake of NR research projects.

Background to the soil fertility workshop

We are in the early stages of a ten year planning horizon for DFID-supported research into renewable natural resources. During the first two years of the programme, much was done to elaborate research priorities for the various production systems, and over £6 million worth of projects has already been commissioned. Soil fertility is a recurring issue across the programme, although emerging with a different perspective in each of the portfolios. It is timely to take stock of our thoughts on the way forward.

NRSP is aware that a great deal of research on soil fertility has been done, in many places over many decades. A great deal of research is also ongoing, within national research institutions in developing countries and also by international research centres. In this context, NRSP will remain a small contributor to a major research agenda. It is therefore of paramount importance that we:

- avoid duplication of effort within the different NRSP production system portfolios;

- support research where the UK has a comparative advantage in terms of experience and expertise; and

- add value to what others have done and are doing.

- develop appropriate partnerships with national and international research centres to promote the outcome of research that will make a real difference to the development process.

In this spirit, the objectives of the workshop are to consult widely about the appropriate objectives that the Natural Resources Systems Programme should be pursuing in relation to soil fertility research. I am extremely grateful for the interest shown by the participants in this meeting to help us in this task, representing a wide range of expertise from within the UK, international research centres and especially from the national research systems of some of those countries where we hope to continue collaborative research.

Maintaining Soil Fertility: Farmers' and Scientists' Perceptions

C. J. Garforth and P. J. Gregory
The University of Reading

Introduction

The term soil fertility includes all those soil characteristics that influence plant growth and impose limitations on yield. Maintaining soil fertility is not just a matter of conserving soil nutrients but involves human intervention to enhance chemical (nutrient availability), physical (texture and structure) and biological (biomass activity) properties and processes. Soils that are inherently fertile have abundant available nutrients, have active biological populations that allow nutrient transformations to occur, and have a structure that allows roots to gain access to the nutrients and water. Management practices that do not take account of these interacting factors are unlikely to result in fertile soils and undue attention to one component may inadvertently lead to an overall decline in soil fertility.

Underlying much of the recent concern about soil fertility and soil degradation is the realisation that despite the recent increases in food production, continued increases will be required to sustain the growing world population. The growth in human population over the past century has been closely associated with an increase in food production (Figure 1). Generally, production has increased slightly faster than population so that, for example, 5.8 billion people today have 15% more food than a population of 4 billion had 20 years ago. Of course this increase has not been uniformly distributed and the number of chronically undernourished has remained relatively stable at about 700-900 million or 20% of the population of less developed countries (Dyson, 1996). Wherever progress has been achieved, it has been mainly due to the alleviation of poverty.

There is now a reasonable degree of certainty in the projections of population for the next 20-30 years but these become increasingly uncertain with time (Fischer and Heilig, 1997). Overall the big changes in demography will occur in the next 2 or 3 decades with slower changes occurring after 2050 or thereabouts. Population will increase by about 0.9 billion per decade for the next 2 to 3 decades with most of this increase occurring in the less developed nations and almost none in the developed countries of Europe and North America. Thus a population of 5.8 billion today will rise to about 8 billion by 2025. There will be large regional differences in the expansion of population with large percentage increases in Africa and West Asia whereas Central Asia will decline in share of population (but not absolute numbers) and South and South East Asia will eventually remain almost constant as a proportion of the total.

There are three major means whereby the projected increases in food and fibre production in the less developed countries will be achieved: first, by expanding the area of cultivated land (extensification); second, intensifying the production system either by increasing the number of crops sown on a particular area of land or by increasing the yield per unit area of individual crops or both (intensification); and finally, where other economic activities allow, by purchasing food from elsewhere. Globally, no one solution will be appropriate and different regions will cope with the increasing population by different means (Table 1 - see also Pound, 1977).

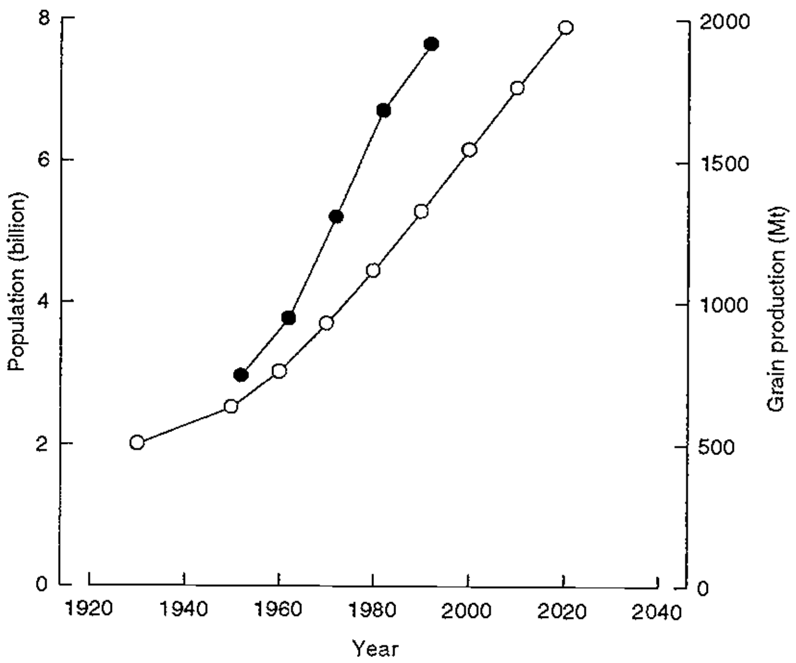

Figure 1. Global changes in population (○) and grain production (●); adapted from Dyson (1996).

Table 1. Expected contributions (%) of various techniques to increasing food production between 1975 and 2000 (from FAO, 1993).

	Extension of cultivated area	Farming intensity	Increased yield/ha
Africa	27	22	51
Asia	10	14	76
Latin America	55	14	31
Middle East	6	25	69
90 Developing Countries	26	14	60

Given the close association of population and food production, it is possible to estimate the required grain production (wheat, rice and maize together supply about 60% of the total carbohydrate). Population growth of 100 million per year (1 billion per decade) requires an annual expansion in grain production of about 32 million tonnes; more if allowance is made for rising affluence. The principal conclusion of most such analyses is that yields per unit area of cereals will need to increase to meet demand from the current 2.7 t/ha to 4.2 t/ha. For this to occur, the inputs and efficiency of use of water and fertiliser on existing cultivated land will need to increase. Farmers' knowledge and skill in managing soil fertility and available sources of nutrients will be a key factor in achieving this.

Farmers' knowledge

It is inappropriate to over-generalise about farmers' knowledge of soil fertility and its management. Farmers' knowledge is essentially local, based on observation and experience within specific farming systems and agro-ecological contexts; and shared within local communication networks. It is unevenly distributed within rural communities because of differences in cultural and socio-economic characteristics (including gender), farming experience, education, contact with external sources of information, economic constraints and priorities, and communication patterns.

Knowledge in this context can be seen as including five different but related facets:

- facts - things which a person or set of people "know" to be true; these can be highly specific and local ("this soil is useless for maize") or more broadly applicable ("soils of type x are deficient in nutrient y").
- concepts and conceptual frameworks - abstract categories through which the elements of factual knowledge are organised.
- taxonomies and classification systems.
- theories - generalised explanations which link elements of knowledge in cause-effect relationships.
- operational knowledge and cognitive skills - how to perform an activity, or how to decide on a response to a set of circumstances (such as declining yields of a crop).

We know more about farmers' soil classification systems, and their operational knowledge (particularly in respect of physical soil and water conservation practices), than about other facets of their soil-related knowledge. In the literature, little attention has been paid to the knowledge which underpins farmers' practices (Sandor and Furbee 1996). Garrity *et al.* (1995) make the related point that scientists have done little to further our understanding of nutrient cycling within agroforestry systems developed by farmers. Tiffen *et al.* (1994) analyse the factors which influence the level of use of FYM in Machakos District, Kenya, but say nothing about the knowledge which informs practice. More generally, Scoones and Toulmin (1995) discuss socio-economic and institutional factors that are key determinants of nutrient flows in dry mixed farming systems in Africa (including tenure, herd size, manuring contracts, social relationships, household structures and population density) but again say little about knowledge and its distribution. Similarly with respect to soil and water conservation practices in Africa, the 27 case studies in Reij *et al.* (eds., 1996) have little information on farmers' knowledge *per se*. Coulter's (1997) review of what we know about dryland soil management in sub-Saharan Africa also finds no reference to information on farmers' knowledge of fertility and nutrient management.

It is important not to infer knowledge from practice. Gregory and Harris (1997) note, for example, that what is reported as "green manuring" in African farming systems may often simply be the burying of weeds during weeding (cf., in Asia, the wide variation in interpretations of what green manuring entails, between and within the four study areas in Garforth and Lawrence (1997); while intercropping is frequently practised in intensive farming systems, not deliberately to maintain soil fertility, but simply to maximise the use of scarce land. Even the use of organic inputs is not necessarily a deliberate attempt to enhance fertility, but is often an incidental result of another practice. On the other hand, crop rotation <u>is</u> practised specifically to maintain or improve fertility, as is the ploughing in of grass at the end of a short seasonal fallow in parts of Kenya (Gregory and Harris, 1997).

Who knows what?

The phrase "local knowledge" or "farmers' knowledge" should not be taken to imply that knowledge is uniformly distributed and consistent within a given area or population. In Sinkana's (1994) study in northern Zambia of farmers' knowledge of soils, each farmer was found to be familiar with only an average of three soils: although they often knew the names of others, they could not describe them in any detail. There are frequently gender differences, both in knowledge relating to soil fertility management and in access to the resources needed to put knowledge into practice: Gregory and Harris (1997) note, with reference to northern Ghana, that "women's access to manure ... is limited and socially complex". By contrast, in parts of Karnataka in south India, Lawrence (1997) reports a higher proportion of women than of men using organic manure.

Within any rural community, some individuals are locally recognised as more knowledgeable than others on specific matters related to agriculture (Subedi and Garforth, 1996). In their study of intensification of farming on the Jos Plateau, Phillips-Howard and Lyon (1994) mention "'expert' individuals" - often older Hausa males - who are particularly knowledgeable about organic and inorganic fertiliser use. They go on to note that some more educated individuals and non-Muslim women who had begun dry-season farming were now acquiring this knowledge from "established farmers". In southern Mali, on the other hand, Defoer *et al.* (1996) found differences in knowledge were less significant than differences in resource endowment in differentiating between standards of fertility management. In their study, "good fertility management" was defined by farmer informants as including above average levels of compost and organic manure production, use of leaf litter, and erosion control measures.

Phillips-Howard and Lyon (1994) observed considerable differences, both within and between villages, in farmers' ways of coping with shortages of inorganic fertilisers, concluding that these "reflected different values, gender roles and traditions" as well as economic factors such as variations in accessibility and the availability of fallow land. Scoones *et al.* (1996) refer to the fundamental trade-off between soil-nutrient management and soil-moisture management which explains a lot of the variations in local soil water conservation practice between sites. Swift *et al.* (1997) note the considerable variations in farmers' soil fertility management practices even within small areas.

Similarly, the indicators that farmers use to assess changes in soil fertility status vary from place to place. Dejene *et al.* (1997), from their study of farmer perceptions of land degradation in Tanzania, note that farmers use many different indicators ranging from changes in species composition to changes in crop leaf colour, pointing out, however, that "most plant species indicators are local and site specific".

Knowing and doing

Phillips-Howard and Lyon (1994) found that most farmers in the three villages of the Jos Plateau Nigeria that they studied in 1991-92 were familiar with the practice of composting. They suggest it may have been a widespread practice in the area at some stage in the past: few farmers were now using it because of the high labour costs. In a village case study from Tamil Nadu, Lawrence (1996) reported that farmers had abandoned the traditional practice of sowing a green manure crop after rice because of theft and damage by livestock - pointing out also that continued subsidies were encouraging the overuse of chemical fertilisers. Similarly, although farmers in bush fallow systems in the forest zone of Ghana recognise that leaving the trash from cleared trees *in situ* would benefit soil fertility, they burn it because of the high labour costs of subsequent re-clearance in the years before the land reverts to fallow (Gregory and Harris, 1997). It is not recorded, however, whether farmers have any knowledge or perception of other, more direct, negative consequences for soil structure and fertility of trash burning.

Application of knowledge in practice is obviously influenced both by farmers' assessment of costs and benefits, and by changes in their circumstances. Lawrence (1996) found that in the face of decreasing availability of organic matter generally and farmyard manure in particular, resource poor farmers were selling manure rather than putting it on their land. In Machakos District of Kenya, Tiffen *et al.* (1994) noted an increasing acceptance of composting (promoted by several non-governmental organisations) in response to the growing scarcity and cost of manure.

Knowledge is more detailed and stable in longer-settled areas. In the Colca valley in Peru, where terraces have been farmed for over 1500 years, Sandor and Furbee (1996) report that a coherent body of knowledge underlies traditional soil management practices. In many long-settled areas which come under population or environmental pressure, knowledge and practice have proved flexible and adaptable enough to maintain or increase productivity in an apparently sustainable manner. On the Jos Plateau, Phillips-Howard and Lyon (1994) identify a long list of combinations of organic and inorganic fertilisers that farmers have used to good effect (alongside other practices such as switching to less demanding crops and adjusting spacing) to sustain soil fertility in the face of intensification of production. Similarly, Box (1989) reported that farmers in the Dominican Republic changed cassava varieties in response to declining soil fertility. In areas which have been more recently settled for permanent agriculture, such as upland areas in parts of the Philippines (Lawrence, 1995; Lightfoot *et al.*, 1989), there is much less knowledge of how to cope with declining soil fertility.

Farmer knowledge itself is not, of course, static. It develops as farmers learn new things, both from their own practice, observation and experiments, and from other people. Lightfoot *et al.* (1989), for example, describe a farmer participatory research process in which trials were designed on the basis of farmer "hunches" that "a sequence of legume species will first control cogon and then regenerate soil fertility and also be easier to cultivate" compared to a grass fallow. Defoer *et al.* (1996) in Mali noted, during discussions on the various soil fertility management practices used by farmers, that their farmer-informants displayed a combination of "local knowledge" and information gained from extension services (and, presumably, other non-local sources - cf. Scoones *et al.*, 1996)

Knowledge underpinning practice

Our greatest area of ignorance is about the knowledge which underlies both farmers' practice, and their reactions to new or adapted technologies. There are some insights, particularly from the farmer participatory research activities of recent years, but little systematic research. We still know little, for example, about how farmers conceptualise and explain plant nutrition and consequent requirements for soil fertility management.

Several studies suggest that farmers are aware of the fertility-enhancing effects of existing practices. Farmers in central Philippines who practice crop rotation and green manuring see yield increases and maintenance or improvements in soil fertility as their main reason for doing so. The same is also true for agroforestry among lowland farmers although for upland farmers, erosion control is the most frequently mentioned reason (Garforth and Lawrence, 1997). However the same study shows that the majority of both farmers and extension workers in study locations in the Philippines, Bangladesh and India regard inorganic fertilisers as essential to increase production. Farmers in Honduras and El Salvador see the benefits of using Inga species as shade trees for coffee as including the fertiliser effects of leaves, positive effects of leaf litter on regulating weed growth and erosion, and better coffee root growth under an Inga mulch (Lawrence and Zúniga, 1996). Swinkels *et al.* (1997) observed that farmers know that sowing sesbania in cropland enriches the soil (although their main purpose in doing so was to produce fuelwood); and yet none of them sowed it in the year before fallowing (which is done deliberately to restore soil fertility).

This absence of information on farmers' underlying knowledge leaves room for speculation and apparently conflicting conclusions - reflected in two of the papers prepared for this workshop. Pound (1997) notes that several recent reviews on soil fertility issues "recognise the high level of local knowledge (and classification) of soils, and point out that some indigenous soil fertility maintenance, and soil and water conservation practices, are being lost". On the other hand, Gregory and Harris (1997 - also Harris, 1997), based on a survey of 213 community development groups in 24 sub-Saharan African countries and fieldwork in Ghana and Kenya, found "little evidence of a sophisticated and indigenous knowledge of sustainable soil fertility management"; and go on to suggest that "lack of knowledge about organic soil fertility management was an important reason for non-adoption of improved soil fertility management techniques" - it was the most frequently mentioned reason in the replies to the postal questionnaire, at least three times more frequent than any other.

There are calls (Wood *et al.*, 1997; Pound, 1997) for extension support for farmers to focus on assistance in making choices and reaching decisions, rather than promoting technical packages or recipes (cf. the advocacy by Swift *et al.* 1997 of decision trees to synthesise and present research-based information). This recognises the inherent variability and site-specificity of appropriate management practices. However there are implications here for the knowledge base and cognitive skills which farmers need in order to be able to use such support effectively. As with integrated pest management, the inherent knowledge-intensity of integrated nutrient management demands well designed learning programmes through which scientists, extension personnel and farmers can build a shared understanding of the processes and factors which determine local soil nutrient status and requirements.

Soils and crop production

From a scientific perspective, increasing crop production raises a range of issues in relation to raising yields, sustaining yields, intensifying systems, and sustaining farming systems. No one solution will answer all problems but several general principles are beginning to emerge which are highlighted in several of the papers presented at this conference (*e.g.* Harris, 1997; Pound, 1997; Wood *et al.*, 1997). The increased production will inevitably mean that both inputs and offtakes of nutrients will increase. The production of 1t/ha of cereal grain means a removal from the field of about 20 kg N/ha and about 4 kg P/ha. Between 1950 and 1989, fertiliser use increased from 14 million to 146 million tons and was a major factor (together with improved genotypes and irrigation) contributing to the three-fold increase of grain production in that same period. Evans (1993) has shown that although the law of diminishing returns applies to the response of cereal yields to increased fertiliser use at a field scale, in the majority of countries there is a linear relation between fertiliser use and cereal yield.

However, there is increasing evidence that while fertilisers may increase yields in the short term, this is not sustainable for prolonged periods. Generally, the few long-term experiments that have been conducted in the tropics show that the use of inorganic fertilisers over periods of 10 to 30 years have failed to maintain yields (Greenland, 1994; Greenland *et al.*, 1998). Adequate amounts of organic manures not only maintained but increased yields, and often enhanced them further when inorganic fertilisers were added. Recent work by Palm (1995) demonstrates that while low maize yields might be sustained using organic materials harvested from forests and agroforestry enterprises, there was insufficient P in all of the materials tested to sustain maize yields of 2t/ha using reasonable rates of application. She concluded that inputs of inorganic P would be required in much of eastern Africa to sustain yields.

The intensification of production systems may also create soil-related problems as, for example, in the development of rice/wheat systems in the Indian sub-continent. Here, soils which are puddled to reduce macroporosity and create a pan at shallow depth in the monsoon season are used to produce irrigated wheat during the winter. The poor tilth of the surface and the shallow cultivation pan are inimical to the production of high yields of wheat and the poor drainage has combined with over-irrigation to render large areas saline (Wood *et al.*, 1997; Abrol and Gupta, 1997). The interaction of physical conditions with biological and chemical processes is frequently ignored in fertility studies but frequently limits the degree of intensification that is possible.

There have been several attempts to calculate the sustainability of current production systems particularly in semi-arid regions of sub-Saharan Africa where water supply is erratic and soil nutrient reserves are low. For example, Stoorvogel *et al.* (1993) calculated nutrient balances for arable land in 38 countries of sub-Saharan Africa and concluded that there is gross nutrient mining throughout. Average nutrient losses exceed inputs and by the year 2000 will be 26 kg N, 3 kg P and 19 kg K ha^{-1} a^{-1}. This net imbalance is currently at the expense of soil reserves and is, therefore, unsustainable unless it can be reversed with judicious use of crop residues, manures and inorganic fertilisers. However, the ability of animal manure to supply the nutrients required is limited. Fernandez-Rivera *et al.* (1995) estimate that if all animals were used for manure production, there would be an average of 680 kg manure per ha per annum for 7 West African countries. This rate of manure production is only sufficient for maintaining fertility in 18% of the presently cropped area at current levels of production. Williams *et al.* (1995) also conclude that manuring alone cannot sustain crop yields and that inorganic fertilisers are needed.

All of these considerations have led many researchers to conclude that the integration of organic manures and inorganic fertilisers (integrated nutrient management) will be necessary if sustainable production systems are to be possible in the tropics. While the environmental costs of inorganic fertilisers have received significant negative attention in Europe and North America, it is also worth bearing in mind that the nutrient losses from purely organic systems are not trivial and that the significant advantages which can be obtained from manures are only realised at greater costs, in land to produce the organic matter, and of labour to collect and spread it. Given the relative scarcity of organic materials in many places, it is important that they are used to maximum effect.

Conclusions

Soil fertility will only be maintained and enhanced by the actions of farmers. Biophysical research shows that means of integrating organic and inorganic nutrient management need to be developed if sustainable production is to occur at the levels of yield that will be required. This raises issues relating to the trade off between short and long-term benefits, and to land and labour availability to produce and handle manures and composts.

While some generic basic research, and long term, single site experiments may be needed to increase our understanding of the scientific basis of integrated nutrient management, much of the research and development work will necessarily be done at local level. This highlights both the need and the opportunity to integrate the perspectives and knowledge of scientists and farmers. Scientists can learn from farmers about local soils and available nutrient sources, and must first understand the rationale for what farmers currently do before they can expect to offer improvements to farmer practice. Similarly, attempts to influence future practice with new scientific information will be more effective if they are based on a clear understanding of how farmers conceptualise nutrient management and plant nutrition. Currently, however, there is little systematic information available on farmers' knowledge in relation to soil fertility and its management.

This suggests that:

1) all locally based scientific research on nutrient management should include an analysis of farmer's knowledge, including its distribution.

2) investigation of farmers' knowledge should move forward from documenting soil management practices and classification systems, to understanding the conceptual and theoretical frameworks which underlie practice;

3) future reviews of RNRRS-funded soils research should include an overview of information on farmers' knowledge, so that any emerging patterns and general findings can be identified and guide investigations in future projects.

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An overview of soil fertility reviews

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Introduction

Over the past 6-7 years reviews of soil fertility have been commissioned by several DFID Programmes and Production Systems of the RNRRS, including the NRSP. To ensure that information is used optimally, and duplication minimised, this overview was commissioned to summarise and synthesise the results of existing reviews.

The 13 reports selected for review by the NRSP, are as follows:

Paper number	Author, date and title of paper
1	Coulter JK 1971 Soils of Central Africa: A Review of Investigations of their Fertility and Management. Land Resources Division, Tolworth, UK.
2	Floyd CN 1991 The Use of Crop Residues to Improve Soil Fertility in Sub-Saharan Africa. Chatham: NRI (for Agronomy and Cropping Systems Programme).
3	Yates RA and Kiss A 1992 Using and Sustaining Africa's Soils. Agriculture and Rural Development Series No 6. Washington: The World Bank.
4	Anderson LS and Bell SA 1995 Definition of the Researchable Constraints to Improved Productive Potential and Sustainability of Land Use Systems at the Forest-Agriculture Interface. Bangor: UCNW (for the Plant Sciences Programme).
5	ICRAF 1994 The African Highlands Initiative: A Conceptual Framework. Nairobi: ICRAF.
6	Kiff E, Turton C, Tuladhar JK and Baker R 1995 A Review of Literature Relating to Soil Fertility in the Hills of Nepal. Silsoe, Beds: SRI (for NRSP Hillsides System).
7	Turton C 1995 An Analysis of Soil Fertility Systems in the Hills of Nepal. Silsoe, Beds: SRI (for NRSP Hillsides System).
8	Gregory PJ 1995 A Strategy for Soil Fertility Research at Lumle. In: Proceedings of a Workshop held in Lumle Agricultural Research Centre, Pokhara, Nepal. 17-18 August 1995. Silsoe, Beds: SRI (for NRSP Hillsides System).
9	McBride (Ed.) 1995 The Foundation for a Refocussed Soil Management Collaborative Research Support Programme. USAID
10	Yates RA and Gibberd G 1995 Literature Review of Fertility Maintenance in Africa. London: ODA (ASC-funded for IBRD study).
11	Gregory P, Nortcliff S and Livesley S 1996 Review of Soil Fertility with Regard to the Forest/Agriculture Interface System. Chatham: NRInternational (for NRSP F/A I System).
12	Morse K 1996 A Review of Soil and Water Management Research in Semi-Arid Areas of Southern and Eastern Africa. Chatham, UK: NRI Chatham: NRInternational (for NRSP Semi Arid Production System).
13	ODA/World Bank 1996 Soil Fertility Management in Sub-Saharan Africa London: ODA (Regional study funded by ODA and managed by the World Bank).

N.B. Summaries of each report were given as an Annex to the full version of this paper distributed at the Workshop.

[1] There are 12 RNRRS Programmes: Natural Resources Systems; Crop Production Research, Crop Post-Harvest;Plant Sciences; Forestry Research; Animal Health Research; Livestock Production Research; Aquaculture Research; Fisheries Management Research; Fish Genetics Research; Fish Post-Harvest Research; Environment and the Flexibility Fund. These Programmes are further sub-divided into a number of Production Systems. The full list of Production Systems is: Semi-arid; High potential; Hillside; Forest-agriculture interface; Land-water interface; Periurban interface; Socio-economic methodologies; Moist tropical forest.

General Conclusions

All reviewers agree that soil fertility is a priority concern, requiring immediate action. The problems most commonly mentioned by reviewers are:

1. The inherent low nutrient status of weathered tropical soils.
2. The rapid loss of soil organic matter due to continuous cropping, burning and overgrazing.
3. The losses of nutrients through erosion and leaching.

Many of these are a result of increasing populations, poor policy frameworks, and unsustainable and intensifying agricultural practices.

More specific areas of concern identified in the reviews are:

1. In sub-Saharan Africa, nutrient mining over decades is a serious constraint to land productivity.
2. At the forest margins unsustainable slash and burn practices are depleting nutrient reserves at a rapid rate.

Key areas for research arising from the reviews include:

1. The interaction between nutrients and water supply to crops (especially in semi-arid areas).
2. The interactions between fertility and genetics.
3. The interactions between components of farming systems (e.g. crops, livestock and forestry).
4. Phosphorus is a key element in many situations. Several papers suggest further study and exploitation of local rock-phosphate deposits.
5. Increased use of mineral fertilisers, often in combination with organic materials, taking care to avoid acidification and nutrient imbalance.
6. Responses to micronutrients.
7. Policy issues (e.g. land tenure and distribution, investment in infrastructure, liberalisation of input supplies, forest legislation), which can profoundly affect soil fertility decisions.

Several papers recommend changes to the way in which research is conducted:

1. Participation by farming families in soil fertility research and development decisions is seen by several reviewers as vital to successful technology development and adoption. Several reviewers recognise the high level of local knowledge (and classification) of soils, and point out that some indigenous soil fertility maintenance, and soil and water conservation practices, are being lost.

2. Integrated Nutrient Management is suggested as an appropriate approach to whole farm fertility maintenance and improvement[2].

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[2] Integrated Nutrient Management combines organic and mineral methods of soil fertility with physical and biological measures of soil and water conservation, and integrates technologies that are adapted to site specific agronomic and socio-economic circumstances to redress nutrient imbalances and soil organic matter deterioration.

3. Soil and water management recommendations that are general, and not site specific, are not seen as helpful. Research must develop options that are sufficiently flexible to cater for local circumstances, and extension must be re-cast to assist farmers to make the best decisions for their situations.

4. Several papers highlight the constraint of information availability to researchers, and the low level of use of historical data when developing research programmes.

5. Inter-donor co-ordination of soil fertility research is poor, and inter-institutional networking of soil fertility experience should increase.

Synthesis of the Reviews by Geographical area and Production System

Geographic and Production Systems' spread of the reports under review

The thirteen reports reviewed here were distributed between geographical areas and RNRRS Production System as follows:

Distribution by geographical area:

Africa	7 (Nos. 1,2,3,5,10,12,13)	Asia	3 (Nos. 6,7,8)
Latin America	2 (Nos. 4,11)	Pan-Tropical	3 (Nos. 4,9,11).

Distribution by RNRRS Production System:

Semi-Arid	7 (Nos. 1,2,3,9,10,12,13)	High potential	2 (Nos. 1,5)
Forest/Agric.	3 (Nos. 3,4,11)	Land/Water	None
Hillsides	4 (Nos. 5,6,7,8)	Peri-urban	None
Moist forest	None	Socio-econ	None

Conclusions by geographical area:

Sub-Saharan Africa

Seven of the thirteen papers reviewed refer specifically to sub-Saharan Africa. Tables 3 and 4 below synthesise the main development issues, institutional issues and researchable constraints identified by the papers.

Table Three: Development and Institutional issues for sub-Saharan Africa

A. Development Issues
• Population growth leading to pressure on land resources and serious mining of nutrient resources.
• Urgent need to build African soil fertility and maintain increased levels of productivity.
• Intensification of production methods and the conversion of marginal lands to arable production, the displacement of pastoralists and increased migration.
• Farmer financial resources and poor distribution systems limit fertiliser use to a very low level.
• Insufficient organic residues available to maintain levels of nutrients at optimum level.

B. Institutional issues
• Weak research, extension, input supply and marketing institutions, contributing to the problem of poor technology identification, dissemination and use.
• Much of the soil fertility research carried out on-station. Greater participation of farmers needed to develop sustainable land-use systems.
• Poor flow and use of information. Some information inaccessible due to language or lack of suitable systems to access international information (CD-ROMs). Practice of comprehensive literature reviews should be revived. Some information, in country (particularly older grey literature), is being lost, and is generally undervalued. Other information, in the hands of ex-colonial countries (e.g. soil maps), should be made more available by those countries.
• Improved co-ordination between donor-driven research efforts is necessary, as is networking between institutions (national, international and NGOs).
• Research could be made more effective by improving methods (e.g. site selection, site characterisation) and allowing longer time horizons, especially for research into the effects of organic matter on soil systems.

Researchable constraints identified by the eight papers dealing with Africa are synthesised in Table Four below. The numbers in parenthesis in the last column refer to the number of the paper in which the constraint was identified.

Table Four: Researchable constraints for sub-Saharan Africa Semi-Arid Production Systems

PROBLEM	CAUSE	POSSIBLE SOLUTION	RESEARCHABLE CONSTRAINT
Low productivity	Low soil nutrient status	Increase inorganic fertiliser use	(a) Identify way to overcome obstacles to increased fertiliser use (technical, economic, institutional). (1) (b) Identify mixtures of cash and food crops that optimise fertiliser use, (1), (5). (c) Studies on local fertiliser prod. (e.g. rock phosphate) (3). (d) Use of non-industrial techniques for increasing the solubilities of native rock phosphate. (10). (e) Investigate combinations of inorganic and organic sources of nutrients. (2), (13). (f) Synthesise past research and identify gaps. (5). (g) Find ways of sychronising nutrient availability/needs. (5). (h) Find more productive ways of using available nutrients (high value crops, rotations, crop-tree-livestock interactions. (5). (i) Re-evaluate FAO country fertiliser programmes. (10). (j) Identify ways of increasing fertiliser-use efficiency. (13). (k) Identify extent of micro-nutrient deficiencies. (13). (l) Develop a GIS capability to model the flow of nutrients, the effectiveness of fertiliser recommendations and the growth of the major food crops. (13). (m) Implement a technical and economic programme to evaluate the long-term residual benefits from the use of local mineral reserves (e.g. rock phosphate). (13).
	Low soil organic matter	Increase SOM	Determine the extent to which OM composition influences soil fertility. (2). (10). Investigate crop residue effects on soil biomass activity. (2). Identify the range of SOMs that can be achieved under a range of conditions using modelling. (2).
	Soil acidity, low ECEC	Increase SOM	Determine the potential of SOM to counteract soil acidity. low ECEC. Al toxicity. (2)
	Poor soil mgt.	Improve farmer knowledge	Development of location-specific nutrient management recommendations. (2). Investigate effects of cultural techniques on dynamics of SOM (e.g. burning, minimum tillage, mulching, bush fallowing). (10).
	Moisture status of soils	Adapt plant genetics	For semi-arid areas develop varieties that establish quickly. thereby covering soil and developing a robust root system. (12).
		Improved tillage	Develop moisture conserving tillage techniques. (12).
		Harvest water	Develop rainwater harvesting techniques. (12).
	Pests and diseases	Increase plant health through improved soil fertility	Develop management strategies based on integrated crop and soil management. (5).
Land pressure	Population growth	Intensify systems	Identify ways of intensifying systems without degrading natural resources. (1),
Low productivity of poor soils	Lack of research	Increase research	Identify reasons for low productivity of poor soils (e.g. sandveldt). (1).
Degradation of soils	Soil erosion	Reduce erosion	Identify methods for soil erosion control, thereby contributing to the maintenance of soil fertility. (1), (5), particularly non-mechanical methods, including leys, cover crops. relay crops, intercropping and rotations (10), hedgerows and trashlines. (12).
Lack of recognition of local knowledge	Research approaches	Change approaches	Explore and harness diversity of native agriculture (e.g. termite mounds) (1) and dambos, sodic lands. (12).
Lack of knowledge of farmer practice	On-station research emphasis	Work with farmers	Obtain better understanding of farmers practices: e.g. crop residue use. (2).

Asia

Three papers deal specifically with Asia. All three were components of one project that formed part of the NRSP Hillsides Production System portfolio. The project was "A systems analysis of soil fertility in the hills of Nepal", and its purpose was to develop a medium-term soil fertility research strategy for the hills of Nepal. The conclusions from these papers are reported below under the "Hillsides" Production System.

Latin America

None of the papers reviewed were specifically based on Latin American soil fertility situations. Those that are most relevant to Latin America are those on the Forest/Agriculture Interface, for which a synthesis is presented below.

Conclusions by Production System

Semi-Arid Production System

The conclusions summarised above under sub-Saharan Africa (Tables Three and Four) can also be applied to the Semi-arid Production System, as almost all of the papers for Africa were focused on the difficult problems facing the seasonally arid areas which make up the greatest proportion of that part of the continent. No papers dealing with semi-arid parts of other continents were reviewed.

Hillsides Production System

Of the four papers relevant to the Hillsides system, three formed components of one project ("A systems analysis of soil fertility in the hills of Nepal"), while the other was the framework paper for a regional initiative to reduce land degradation and raise productivity in the highlands of eastern and central Africa.

Development issues: Nepal

- Hill land-use (in Nepal) also affects downstream users (in India, Bangladesh).
- Changes in policy (infrastructure development, commercialisation, forestry policy, land tenure and fertiliser supply) have profound effects on hill agriculture.
- Land holdings are small, leading to increasingly intensive use of arable land.
- Farmers, in general, see soil fertility declining.
- Land tenure status important in decision-making on soil fertility maintenance practices.
- Interdependence between crops, livestock and forestry.
- Indigenous soil fertility maintenance techniques in place, but some being lost.
- Concern over the institutional separation of research and extension.

Development issues: Africa

- Declining land productivity.
- Encroachment of agriculture on fragile land-forms (valley bottoms, steep slopes, wetlands, forests).
- Diminishing capacity to support growing population.
- Failure of Training and Visit extension system.

Researchable constraints for Hillsides systems in E Africa and Nepal are given in Table 5 overleaf:

Table Five: Researchable constraints for the Hillsides Production System

PROBLEM	CAUSE	POSSIBLE SOLUTION	RESEARCHABLE CONSTRAINT
A. E. and Central Highlands (Paper 5)			
Declining soil productivity	Existing resource management system; inappropriate national agricultural policies; internal strife; high cost of inputs	Maintenance and improvement of soil fertility	a) Synthesis of past research b) Reduction of nutrient losses c) Improved recycling of nutrients d) Ways for making greater productive use of available nutrients
		Strategies to protect crops from pests and diseases resulting from declining soil fertility.	Studies on banana nematodes, bean stem maggots, bean root rot, potato bacterial wilt and striga.
		Study indigenous NR management	Diagnostic and socio-economic studies of indigenous NR management
		Increase NARS capacity	Identify weaknesses and support needs

Table Five continued.

PROBLEM	CAUSE	POSSIBLE SOLUTION	RESEARCHABLE CONSTRAINT
B. Nepal (Papers 6, 7 and 8)			
Poor understanding of farmers perceptions	Research approaches	Modify research approaches	a) Devise practical soils classification to include farmers criteria b) Survey reasons for farmers observations of declining fertility c) Understand factors affecting farmers soil fertility decisions d) Understand role of women in soil fertility management
Soil organic matter decline	Multiple	Increase availability and efficiency of use of organic matter	a) Organic fertiliser quality and rates of release, and role in reducing nutrient losses and improving physical condition of soil b) Management systems for compost-producing areas (forest) Investigate ways of producing more compost from cultivated areas c) Determine effective means of conserving nutrients in manures and composts
Low nutrient status of soils	Low inputs; losses to erosion and leaching	Increase nutrient inputs; decrease losses	a) Development of appropriate fertiliser recommendations b) Investigate ways of harnessing nutrients from outside closed farm/village system (e.g. irrigation water, N-fixing plants, common property resources) c) Determine importance of erosion and leaching under different land-use categories d) Devise management practices to reduce erosion and leaching losses using a participatory approach e) Surveys to develop quantitative baseline to understand relative rates of soil fertility decline across agroecological zones and land types
Soil acidity	Chemical fertilisers	Change fertilisers and/or their use	Devise appropriate measures to reduce soil acidity caused by chemical fertilisers
Poor understanding of nutrient cycles	Fragmented research	Co-ordinated research strategy	a) Collate existing information on the nutrient cycles of the farming systems in high, mid, and low hills; identify key sub-systems and initiate research to fill the gaps so that cycles are complete within 3 years. b) Development of Integrated Nutrient Management systems

Forest Agricultural Interface System

Three very different papers are relevant to this production system (Papers 3, 4 and 11). There is concensus that soils that are stable when undisturbed are often precariously fragile following conversion to agriculture, and there is often a rapid loss of soil nutrients and organic matter, followed by a more gradual decline. The majority of forest soils are highly weathered and of inherently low fertility. Shifting cultivation, both in Africa and Latin America, is ceasing to be an option for maintaining soil fertility.

Development issues

- Estimates of forest clearance vary between 3-24.5 M ha/yr. 50% may be due to agriculture, including shifting agriculture, continuous cropping, plantation agriculture and ranching (other losses are due to logging and industrial uses of forest products).
- The likely link between soil degradation and aridity, and the loss of natural vegetative cover.
- Unsustainable practices such as destructive slash and burn agriculture, low-input ranching and destructive logging methods are using forest resources wastefully and causing damage to the environment.
- Need for greater participation of communities in identification and implementation of priorities.
- More effective co-ordination between donors, and between institutions.
- Need for a change in emphasis in agroforestry research towards understanding the processes involved in interactions between components of agroforestry systems. Many of the agroforestry, hypotheses (that have previously been taken as advantages of agroforestry) remain to be proven[4].

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[4] See Table One in the review of Paper 11 (Gregory *et al*, 1996) for a summary of agroforestry hypotheses.

Table Six: Researchable constraints for the Forest/Agriculture Interface Production System

PROBLEM	CAUSE	POSSIBLE SOLUTION	RESEARCHABLE CONSTRAINT
From paper 3			
Low soil productivity	Low soil nutrient and organic matter status	Use of inputs	Investigate interactions between mineral fertilisers and organic/biological sources of nutrients. Study feasibility of local fertiliser production.
From paper 4			
Low productivity of agroforestry systems	Poor understanding of plant interactions and nutrient dynamics	Mechanistic agroforestry research	a) Studies to understand rooting patterns in the context of competition and facilitation. b) Phosphorus as a limiting nutrient, and its links to mycorrhizas and "environmental grain". c) Dynamics of nutrient release from plant litter, and their synchronisation with acquisition and use by crops.
From paper 11			
Degradation of natural resources at the forest margin	Unsustainability of present forest margin agricultural practices	Development of appropriate sustainable practices based on an understanding of soil and crop interactions	**Soil nutrients:** a) dynamics of P in the inorganic/organic soil system. b) consider the application of a wide range of rock based P sources. c) investigate the process of "deep nitrate capture" and to identify the nature of rooting systems required to optimise the efficiency of these systems. d) nutrient budgets at the forest/agriculture interface. e) changes in soil nutrient pools in the post-clearance phase (especially for Oxisols). f) optimum management of organically-based and fertiliser-based nutrient inputs. **Roots:** a) the morphology and nature of tree roots systems necessary to optimise the roots' role in "closing the nutrient cycle". b) the distribution, decomposition and nutrient release patterns of perennial tree and annual crop root systems. c) the interaction between tree and arable crop root systems, both under normal and stressed conditions. The different root architectures and nutrient and water capture strategies must be identified. **Soil organic matter:** a) mechanistic research of the release and immobilisation of nutrients in organic residues added to the soil as soil surface and below-ground additions. b) the nature and composition of plant residues with respect to their "liming" effect, and to investigate response in both field and laboratory environments. c) characterise the nature of tree plant residues, their rate of breakdown, and the release of nutrients during this breakdown, and to synchronise these releases with the needs of the crop plants and soil system. d) demonstrate beneficial effects of fallow tree species and identify the extent to which particular trees may be used for ameliorating soil with respect to particular nutrients. Develop a mgt. strategy on this basis. e) monitor nature and dynamics of soil organic matter and plant litter decomposition over seasons and longer periods.

The soil, water, and nutrient management programme - opportunities for collaboration with UK institutions

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The need to manage land resources more sustainably is now recognised internationally as a major challenge facing mankind. Feeding a burgeoning population projected to reach 9,400 million by 2050 will require a two percent per annum increase in food production. Most of this growth must be achieved in the developing countries against a trend of reduced productivity of soils due to land degradation processes such as: surface soil loss due to wind and water erosion; soil fertility decline caused by nutrient mining; soil physical deterioration; acidification; and salinization. Both high potential and marginal lands in the tropics are affected.

Soil scientists and agronomists have generated a vast knowledge base on the key chemical, biological and physical processes in soil-plant systems that govern land productivity. However, large parts of the knowledge base rest in libraries and databases unused by land managers and decision-makers. This anomaly has prompted research leaders to undertake a fundamental re-examination of the approach to international agricultural research on soil, water, and nutrient management and how the research is organised.

This paper reviews recent progress in developing more effective ways of doing and organising research on sustainable land management. I then describe the CGIAR programme on Soil, Water, and Nutrient Management (SWNM), which was designed to embody the latest thinking. Finally, I discuss the opportunities for SWNM linkages with UK institutions.

The New Research Agenda

Greenland *et al.*, (1994) pointed out that past approaches to SWNM research have produced land management technologies unsuited to the social and economic conditions of farmers in developing countries. The Greenland paper proposed a new agenda based first and foremost on a participatory approach to research that involves the land user in the definition of the problems and the search for solutions. This approach requires the involvement of an interdisciplinary team of social scientists as well as biophysical scientists.

At a subsequent meeting in Zschortau, Germany (DSE/IBSRAM, 1995) representatives of a wide range of research agencies formulated a co-ordinated plan for international research to accommodate the new paradigm. The organisational model adopted was the consortium which draws together research agencies around a common goal or high priority SWNM theme. At the core of the consortium are the farmers, National Agricultural Research and Extension systems (NARES), and Non-Government Organisations (NGOs). These core participants are supported by Advanced Research Organisations (AROs) and International Agricultural Research Centres (IARCs), each contributing according to their comparative advantage (see Figure 1).

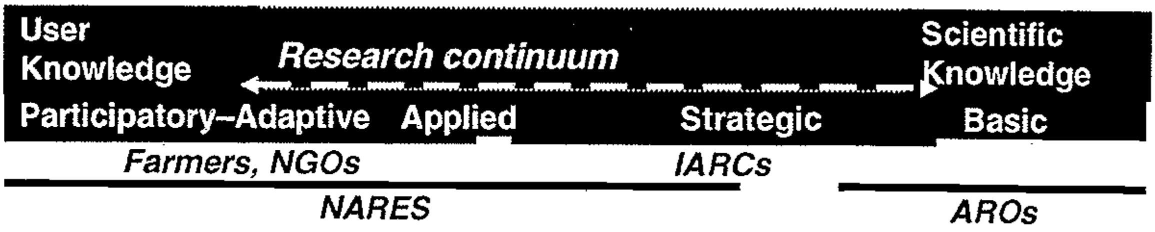

Figure 1. Primary stakeholder domains along the research continuum

The SWNM Programme

The overall *goals* of the SWNM Programme are to: increase long-term agricultural productivity; reduce poverty; and conserve and enhance land and water resources.

The Programme's primary *objective* is to develop effective, sustainable technologies and systems for land management and conservation, which can be made available to farmers and other land users. Important related objectives are to:

- Develop, test, and promote new, community-based institutional mechanisms that encourage the use of sustainable SWNM technologies;
- Through research partnerships, enhance the capacity of all stakeholders to plan and implement programmes on sustainable land management systems;
- Develop and promote policies that take into account equity issues, such as gender, access to resources, and land tenure.

The programme started in 1996 with four consortia:

1. *Combating Nutrient Depletion* – This programme aims at improving the availability and efficiency of nutrient use through integrated nutrient management practices, policy guidelines, and pathways for adoption designed for the African Highlands and the West African Moist Savanna eco-regions. The Tropical Soil Biology and Fertility Programme and the International Fertiliser Development Centre convene the consortium in collaboration with the Kenyan Agricultural Research Institute and Institute for Agricultural Research, Nigeria.

2. *Managing Acid Soils* – CIAT and Empresa Brasilieira de Pesquisa Agropecuaria (EMBRAPA, Brazil) co-convene this programme, which was devised to rehabilitate degraded acid savannas with productive agropastoral and/or sylvoagropastoral systems in the Latin American lowland ecoregion.

3. *Managing Soil Erosion* – IBSRAM and the Centre for Soils and Agroclimatic Research in Indonesia co-convene this consortium aimed at developing acceptable land management practices to minimise soil erosion and its off-site impacts in catchments of the humid and sub-humid ecoregion of tropical Asia. The research will involve a range of stakeholders and generate improved policy guidelines as well as new technologies.

4. *Optimsing Water Use* – the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), the International Centre for Agricultural Research in Dry Areas (ICARDA) and the Institut d'Economie rurale du Mali (IER) designed this consortium to tackle the problem of crop water-use efficiency and water harvesting in semi-arid areas of sub-Saharan Africa and West Asia/North Africa.

Each consortium addresses a global problem, but initially focuses activities in a single ecoregion. Eventually each consortium will expand globally as appropriate. A global SWNM Steering Committee was formed to exploit synergies between the different consortia and exchange information.

The SWNM Programme's *research approach* is based on principles drawn from the Greenland paper, from reports of the CGIAR's Technical Advisory Committee (TAC) on strategies for natural resource management, and from the CGIAR's ecoregional approaches. The key principles include:

- The use of participatory, community-based research;
- A focus on policy and institutional issues influencing decision-making;
- Consideration of equity concerns, including gender analysis;
- Examination of interactions between people, land, and water from plot to landscape;
- Integration of the full research and development continuum;
- Reliance on both indigenous and scientific knowledge;
- Linking of increased production to natural resource conservation.

The consortia will generate the following generic *outputs*:

- Economically viable technologies that are socially acceptable and environmentally sensitive;
- Improved methods and diagnostic tools for participatory research;
- Indicators to monitor the environmental and economic impact of land use-systems;
- Decision support systems, including models, expert systems, geographical information systems, and global databases, for generating, testing, and extrapolating SWNM options;
- Stronger institutional capacity to implement SWNM programmes and policies;
- A framework for partnerships between stakeholder groups;
- Information on appropriate policies to promote sustainable SWNM practices;
- An effective mechanism for information exchange.

In 1997 the SWNM Programme moved to strengthen global links between the individual consortia through enhanced development and sharing of methodologies. TSBF, CIAT and IBSRAM are developing decision support systems and analytical models to assess land quality, guide sustainable land management, facilitate integrated nutrient management, and assess impact. The last area involves an initial focus on developing a framework for the cost-benefit analysis of the on- and off-site impacts of soil erosion (and soil conservation), followed by a similar study on nutrient depletion. By sharing experiences and actively collaborating to exploit synergies across regions, the SWNM consortia will help fulfil the Greenland committee's vision of a reinforced and harmonised global research effort to address major land degradation problems.

Collaboration with UK Institutions

The effective orchestration of the SWNM consortia depends on capturing the interest of collaborating institutions, devising alliances to fill gaps, and securing funds to catalyse the research. A prerequisite for funding is congruence with the development, sectoral, and geographic priorities of the donor agency. In the case of DFID, much of the current Natural Resources Systems Programme shares common objectives and methodological problems with the four consortia of the SWNM, although the geographic coverage is different. Within the DFID programme, the research programmes on Hillsides Production Systems, the Peri-Urban Interface, and Semi-Arid Production Systems most closely match the SWNM interests in soil erosion, nutrient management, and water-use efficiency.

As shown in Figure 1, AROs have much to contribute at the strategic and basic end of the research spectrum. UK institutions have a long history of scientific excellence in the field of soil science and land management. This expertise and knowledge can be put to good effect in support of the consortia of the SWNM Programme, through collaborative research and training. The SWNM consortia offer a problem-solving, development context at chosen benchmark sites, where catchment studies focus on social and biophysical aspects of landscape dynamics. At these sites staff and students from UK research institutions and universities can pursue strategic research. The catchment studies are long term and, because the level of investment is high, need such supplementary research so that the investments are used more effectively. There is a plethora of knowledge gaps that collaborating AROs can help fill through discreet research projects on methodologies, technologies, agro-ecosystem processes, systems analysis, etc. The SWNM global framework also provides opportunities to exchange experience on methodologies and approaches. In this regard, the CGIAR programme on participatory research and gender analysis is also working closely with the SWNM Programme, and both have much to gain from links to the DFID programme on socioeconomic methodologies.

At this workshop other papers will review ongoing programmes of UK institutions and provide an opportunity to assess areas of mutual interest and future collaboration. On behalf of my colleagues in the SWNM Programme, I welcome the opportunity for this dialogue and look forward to forging new partnerships and strengthening existing ones. In the process of the discussions, I hope that we keep in mind the needs of the resource-poor farmers of the developing world, who are our ultimate clients.

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The UK comparative advantage in research and development of integrated nutrient management systems that farmers will use

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Introduction

World food security will only be possible if crop production is not only maintained but sustainably increased and this requires that soil fertility be improved. Also, it is increasingly recognised that soil fertility decline is a major cause of land degradation, linking environmental concerns with productivity dimensions. The most serious problems are in the developing world where pressure on the land and the need for food is the greatest.

The considerable progress made in crop production in the past 30 years has involved improved germplasm underpinned by the greater use of fertilisers and the spread of irrigation. But soil fertility is not just a question of nutrients and water. Maintenance of favourable soil physical and biological properties is also essential; properties which are usually associated with the amount of organic matter in the soil. Recent concerns about the sustainability of crop production systems have arisen because of the loss of organic matter and biodiversity, loss of nutrients and acidification, soil erosion and other physical changes, as well as contamination of land by salt, heavy metals, and pesticides, particularly in peri-urban areas. The most common problems are those associated with loss of organic matter and nutrients (Syers, 1997). This points up the widespread and considerable importance of the development of effective integrated nutrient management systems.

The UK has a strong comparative advantage in assisting developing countries to overcome their soil management problems because of its long involvement in tackling these problems, its strong research base, and the considerable capacity of its universities and research institutions to provide training at all levels in many areas of soil research. There is also a history of effective collaboration between UK-based institutions and national and international research institutions located in developing countries. There is much potential for further collaboration not only with regard to increased crop production, but also with environmental problems related to the sustainability of crop production.

In this paper we review briefly some of the areas where we believe the UK has an established comparative advantage. These are discussed in relation to the five NRSP Production Systems. As a preliminary we make a few comments on general aspects of the UK comparative advantage.

General aspects of the UK comparative advantage

Soil and site specificity require that soil fertility management problems be tackled on a local basis. Support for such work can usefully come from the identification of common approaches originating from strategic and basic research. To identify these approaches and to optimise the use of results, it is essential that strong linkages are built between the locations where the problems exist and the institutions where the necessary underpinning research and training can best be conducted.

The comparative advantage of UK institutions lies in strategic and basic research, and training at advanced levels. The diversity of field sites requires that applied and adaptive research must primarily be the responsibility of the national research organisations, although international organisations such as the Centres associated with the CG System (International Agricultural Research Centres -IARCs) and some others such as IBSRAM can facilitate the development of the necessary linkages. Advanced research organisations (AROs) in the UK already have many linkages to the IARCs and through the IARCs to many of the national programmes with whom they collaborate. A recent Technical Advisory Committee report (TAC, 1997) on "Priorities and Strategies for Soil and Water Aspects of Natural Resources Management Research in the CGIAR " has recommended that " The CGIAR System should develop improved mechanisms by which Centres, collectively, can be involved with other partners ... in generating and interpreting improved scientific evidence .... on degradation or enhancement of natural resources". It was also recommended that "Expanded and collaborative mechanisms and activities (should) be developed among Centres and between Centres and their non-CGIAR partners, to help focus increased research and institution strengthening on issues related to adoption, adaptation and utilisation of existing NRM (Nutrient Research Management) technologies and knowledge that have so far remained unused". IBSRAM was established specifically to address these same problems and has developed several research networks in which the national systems and AROs are brought together to jointly tackle the problems of land management. Building upon and strengthening these linkages will greatly assist realisation of the UK comparative advantage in research on integrated nutrient management.

The sustainable management of natural resources requires that depletion does not occur. For soils this means that their productive potential is maintained or improved. Experimentally this is best studied by conducting long-term experiments, for which the Rothamsted experiments are the outstanding example (Powlson and Johnston, 1994). They provide evidence of the critical importance of appropriate management and have shown that even on such stable soils, integrated nutrient management is essential when yields of wheat exceed 7 t ha^{-1}. Under the less stable conditions of the tropics, the importance of integrated nutrient management has also been shown in long-term trials (Greenland, 1994). Although long-term research is esssential for sustainability studies, and these are often of critical importance, it is difficult to obtain continuing funding, because it may not have short-term impact. It may be best supported by core funding to international centres for work in association with national systems. In the design and management of such trials the UK undoubtedly has a major comparative advantage.

The TAC Report on Soil and Water Management (TAC, 1997) makes a strong case for long-term experiments conducted on a catchment basis. These are required to demonstrate the importance of off-site, as well as on-site effects associated with changes in land management. Here again, the UK has a comparative advantage, the catchment studies in East Africa managed by Charles Pereira being an outstanding example.

Priority soil fertility research issues in the NRSP production systems

(a) Semi-arid

Degradation of soils in semi-arid regions commonly occurs because of deforestation, overgrazing, and overcultivation. Loss of organic matter, salinisation in lower rainfall areas and acidification where rainfall is higher, and a deterioration in soil physical properties (crust formation and structural decline) are the major contributors to soil degradation. The efficiency of nutrient use is reduced by water limitation and inadequate organic material inputs. Erratic rainfall patterns call for improved water management practices, including water harvesting and irrigation.

The UK comparative advantage lies in expertise with nutrient and organic matter dynamics and management, and in the development of water management technologies.

(b) Forest-agriculture interface

Inappropriate land-clearing practices are still used in many parts of the world and this is particularly the case at the forest-agriculture interface. Compaction and loss of soil structure impair crop development and increase runoff and soil erosion, with consequent loss of soil organic matter and nutrients. Lower inputs of organic material cause soil structural decline.

The UK comparative advantage lies in understanding the interactions between physical, chemical, and biological processes in soils, and the ability to model these with a view to developing appropriate management strategies.

(c) High potential

These are the areas of higher rainfall, relatively stable and resilient soils, and the irrigated areas, most notably the areas where irrigated rice is grown. In these areas the dominant importance of correct nutrient management is well established. The role of organic matter is often also critically important, although much further work is needed to clarify its role in different conditions. Some soils of the high potential areas (Cambisols, Luvisols) are resilient to intensive cultivation, whereas other (Ferrasols, Acrisols) are relatively fragile and require particularly careful management to achieve their potential.

The UK comparative advantage lies in studies of nutrient maintenance and the management of soil organic matter, and for irrigated rice soils, where an upland crop is grown after rice, in managing the physical properties of the soil, to achieve a dispersed condition while rice is grown, and a porous condition when the upland crop is grown.

(d) Peri-urban interface

Intensification of agriculture in peri-urban areas creates special soil fertilility problems. Continuous cropping with intensive or inappropriate cultivation frequently leads to a loss of soil organic matter and a deterioration in soil physical properties. Pollution from agrochemicals (particularly pesticides) and heavy metals can lead to the contamination of food and the loss of biodiversity, whilst the overuse of nitrogen and phosphorus fertilisers can cause a decline in water quality.

The UK comparative advantage lies in understanding the interactions of soil organic matter and physical properties, and the transport of nutrients and pesticides in soils. There is also considerable expertise in the soil chemistry of heavy metals and their impact on biodiversity.

(e) Hillsides

Increasing population pressure leads to the unsustainability of sloping lands. This is because cultivation enhances water runoff and increases soil loss by erosion. Productivity declines because of the loss of topsoil which is enriched in organic matter and nutrients. On-site degradation is accompanied by negative off-site effects, including eutrophication and increased siltation and flooding.

The UK comparative advantage lies in understanding, modelling, and managing erosion processes and in nutrient and organic matter dynamics which can be used as a basis for improved integrated nutrient management systems.

Conclusions

The UK has established standards of excellence in research on many aspects of soil research related to immediate production and sustainability problems which can form a sound basis for development. The value and use of the research conducted can be increased greatly if it is associated with research organisations in developing countries, where there is a strong linkage to the realities which farmers experience. Provided that all scientists involved have adequate opportunity for joint planning and evaluation of results, and a willingness to share results fully, the progress made in the research can be much greater than the sum of the parts, and there can be spillover to several other countries.

The Networks of IBSRAM and the Consortia of the CGIAR concerned with soil and land management provide excellent opportunities to forge effective linkages between UK-based Centres of Excellence in soil management research and the countries where that expertise can be used most effectively. But it has to be recognised that a two-way flow is essential; the application of research findings by farmers will generate problems which must be fed-back to the researchers who will conduct the further research needed to resolve the farmer's difficulties. The results of the research must then be tested in the field and evaluated by farmers and others.

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Towards improved methods for integrated nutrient management: the TSBF approach

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Introduction:

The TSBF approach to the problem of soil nutrient depletion is predicated on two basic perceptions:

1. The solution to soil fertility problems requires the combined use of organic and inorganic sources of nutrients in both the short-term, to overcome current production deficits, and in the long-term to achieve sustainable production. Although fertilisers are used in much of sub-Saharan Africa, the amounts applied are insufficient to meet crop demands (Palm *et al.*, 1997). Organic inputs are often proposed as alternatives to inorganic fertilizers. Traditional organic inputs such as crop residues and animal manures, cannot however meet crop nutrient demand over large areas because of the limited quantities available, the low nutrient content of the materials and high labour demands for processing and application. Most farmers in sub-Saharan Africa fall within the two extremes of the organic to inorganic fertiliser continuum and use a combination of organic and inorganic inputs (Table 1). (Yields still fall short of their potential because of inadequate amounts added, the inappropriate quality of the organic materials, and inefficient combinations). Beyond this immediate need the evidence from long-term experiments is overwhelming with respect to the greater sustainability of integrated nutrient management as compared to the use of either source alone (see reviews by Pieri 1995; Greenland 1994, Lal and Stewart 1995, Swift *et al.*, 1994 and Swift 1996).

Table 1. The use of organic and inorganic nutrients in Sub-Saharan Africa.

	Western Uganda[1]	Central Uganda[1]	Western Kenya[2]	Central Kenya[2]	Mutoko Zimbabwe[3]	Shurugwi Zimbabwe[3]
	.... % of farmers					
Inorganic fertilisers	3	4	54	83	98	40
Manures	29	31	79	98	86	65
Crop residues	4	83	72	98	77	--

[1] Bekunda and Woomer, 1996; [2] Crowley and Carter (in press); [3] Murwira et al; 1995

2 Adaptability of resource management technology by African farmers remains low. The causes are complex but fundamental to the problem is the irrelevance of much on-station research to the needs of the farmer and the failure of researchers to recognise the heterogeneity of farm environments and socio-economic circumstances.

We recognise at the outset that research on the biological aspects of soil fertility, if it is to be relevant to the circumstances of smallholder farmers in Africa, has to be undertaken in such a way that it can draw on and contribute to wider development efforts. To this end, TSBF has invested considerable time and effort in trying to understand farmers' soil management strategies and how these relate to their (highly variable) circumstances. This, and a knowledge of evolving thinking on institutional development within smallholder communities (Budelman, 1996), define the arena of relevance for more basic process-based research. Process research is essential if we are to generate new knowledge about the possibilities for farmers to use resources more efficiently and sustainably, and we describe highlights of recent research in the following section. There is increasing awareness amongst many scientists of farmers' experimental activities (Okali *et al.*, 1994). TSBF is just beginning to explore ways to work side-by-side with farmers in their experimentation, to learn with them, to exchange ideas and information stemming from basic process research, and to identify ways to increase and improve the flow of information between farmers and researchers. Some brief details of current activities in this area are outlined below, followed by some ideas on how new knowledge can be generalised and shared beyond specific research sites.

Improved practices for organic matter management

A major objective of this research is to develop options for the combined use of organic and inorganic nutrient sources. These options must be flexible and apply to farmers that use little if any fertilisers, as well as those that use considerable amounts of fertilisers. They must also take into account the differential access of households to labour and cash, particularly the constraints of the poor households where women provide most of the labour in agriculture. The challenge is to present these options in a manner that is useful to extensionists and farmers.

Appropriate combinations of nutrients for soil fertility management must consider the amounts and competitive uses of different organic materials available to an individual farmer, the nutrient supplying capacity of those materials, the type and amount of purchased fertilisers, if any, a farmer normally applies, and the soil type(s) and primary limiting nutrient(s) on the farm. Scientists can then provide information on what are the probable best combinations for a given circumstance; the ultimate choice will nonetheless depend on the farmer's desires. We have identified decision trees as an effective and flexible means of synthesising and conveying this information. Extensionists and farmers play a crucial role in their development and testing.

The basis of this strategy is outlined in Table 2 (Palm, Myers and Nandwa 1997). At the heart of the approach lies the improved scientific advice that can be given on the choice and method of use of organic materials as fertilisers.

Research on organic resource quality factors (eg. see Cadisch and Giller 1997 for references) has shown that the 'fertiliser equivalency' of an organic material can be predicted on the basis of its chemistry. A minimum list of parameters that should be included in resource quality analysis are macronutrient concentrations, lignin, soluble C, ash, and if the N concentration is greater than 1.8% soluble polyphenols. Standardised methods for these analysis are also recommended (Palm and Rowland, 1997). Once a sufficient number of materials of the same species has been characterised to indicate the possible range in quality within a species then it may be possible to categorise a plant material into a specific quality grouping without analysing the material.

Table 2: Research strategy for integrated soil fertility management

On-farm and community surveys

- Soil types and corresponding limiting nutrients
- Availability and types of inorganic fertilisers
- Availability and amounts of organic inputs
- Potential niches for planting non-food legumes

↓

Characterisation of organic inputs

- Nutrient concentrations
- Carbon quality

↓

Establishment of Fertiliser Equivalency Values

- Laboratory incubations
- Field trials
- Multiple nutrient effects
- Relationship to organic input quality

↓

Combination of organic and inorganic nutrients

- Based on fertiliser equivalency values
- Factorial trials
- Optimisation trials
- Long term and residual effects
- Economic analysis

Fertiliser equivalency or nutrient substitution values of organic materials is then determined and related to the quality of the material. Such information is obtained through a combination of laboratory incubations and field trials. Incubations establish the amount of different organic materials needed to attain similar soil available nutrient levels as that of a given amount of fertiliser. Field trials test recommendations from the incubations over a range of different soils and climates; models extrapolate to other types of organic materials and environments.

The significance of the research on the control of decomposition processes by resource quality factors of which the above is an example, is: first that it provides an explanation for the differential effects observed from mulching or fertilising with different organic materials; and second, that it provides the basis for knowledge-based tools for the management of organic inputs. The TSBF Programme in collaboration with Wye College has developed a database documenting relationships of this type. This can be used to make choices between different organic inputs within a given environment with respect to their fertiliser equivalence. These choices can be further widened to include the impact of utilising mixtures of organic materials or more importantly, mixtures of organic and inorganic inputs. The inclusion in such a database of information on the further variance caused by other factors (*eg*. environmental influences such as those experienced in mulching versus incorporation) or effects beyond nutrient supply (*eg*. residual effects on SOM status) could lead to the capacity to manage organic matter with an even higher degree of predictive sensitivity.

The desired outcome of the research process detailed above are fairly simple tools that can be used by researchers, extensionists, and farmers for assessing different ways of using scarce resource for maintaining soil fertility and improving crop yields. An example of one such tool is a preliminary decision tree on the uses of organic material of different quality for N management (Figure 1, Palm *et al.*, 1977). The decision tree is a current best approximation based on research results. It can be modified as more information becomes available but more importantly implemented with farmers' and modified based on their experiences and available resources.

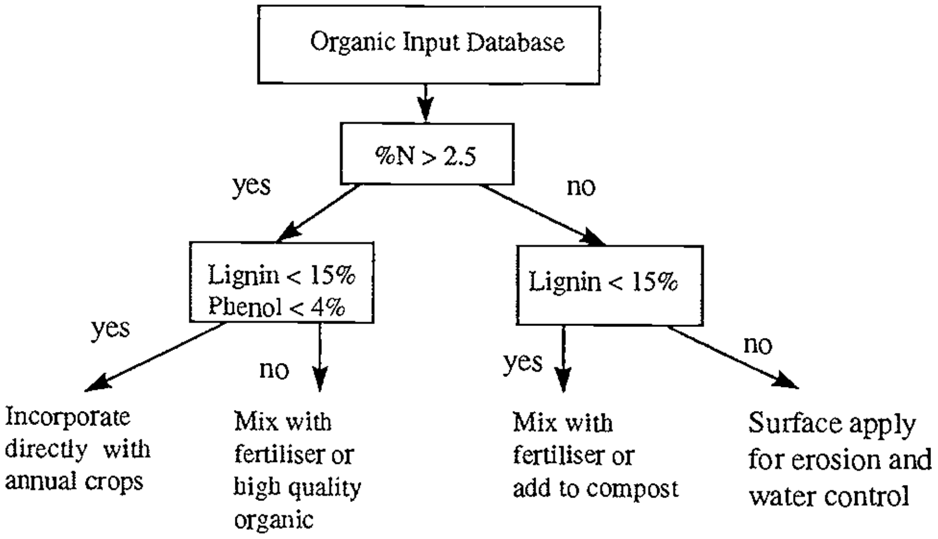

Figure 1: Organic Matter Management Decision Tree for Nitrogen (Palm et al., 1997)

Adoption and Dissemination

The type of biological research alluded to above is conducted at farm sites selected on the basis of field research that has been conducted over a number of years. These have shown the possibility of defining typologies of farms with respect to the practices of soil fertility management which farmers utilise (and which vary considerably within a small area) and the factors which determine them (Carter and Murwira 1995, Bekunda and Woomer 1996, Carter and Crowley 1997 in press).

The on-farm experimentation with different combinations of organic and inorganic materials lays a basis with the farmers and extension agents (including NGOs) for the dissemination of successful practices within the immediate vicinity. Some components of the methods adopted to facilitate this process include:

- targeting on-farm research more effectively using available socio-economic and biophysical information about the area through GIS;

- increasing frequency of consultation between farmers, NGOs and researchers to improve the relevance of research direction and technical recommendations;
- involvement of all parties in the design and modification of on-farm trials, it is an essential point to realise that all parties have important but different roles to play;
- increasing the capacity of NGOs and farmers to experiment;
- working with farmer and community groups that have been involved in participatory research in the earlier stages of this work.

There is considerable uncertainty about how research findings can be usefully generalised (or extrapolated). Confidence in the usefulness of GIS databases as tools for extrapolation of technology appears to contradict the widely held dissatisfaction with top-down technology transfer (Carter *et al.*, 1994; Chambers, 1997). Yet there is a need for researchers to address the issue of generalisation. In its simplest form the argument is that good ideas or innovations will spread on their own, albeit in modified forms, and research has an important role to play to help speed up this process.

We recognise at least two components to this process of generalisation. The first, upon which much of our socio-economic and cultural-ecological research has focused (Carter and Murwira, 1995; Crowley and Carter, in press; Carter and Crowley, in preparation), is to identify and understand social and spatial patterns of resource management and their dynamics. This knowledge can, for example, be used to erect typologies of farm households based on resource management strategies in order to identify client groups that could benefit from specific research findings (findings, that is, as knowledge of principles and processes, rather than as finished technologies). The second component is less tangible but probably more important, and relates to situating the process of generalisation within broader initiatives to strengthen local institutions for development; it looks for ways of passing on information more efficiently, for building links with institutions that try to strengthen farmers' own research capacity, and for improving communication between research and grassroots institutions.

Implementation:

TSBF research in nutrient management has been implemented through its network (AfNet) in eastern and southern Africa with a particular focus in Kenya and Zimbabwe. More recently links have been established between this network and other international (eg. CGIAR) and national agencies through the SWNM Programme of the CGIAR within which TSBF with IFDC has the leadership for nutrient management research. The research referred to here has been largely supported by the Rockefeller Foundation, IDRC and the EU; and more recently by the donors to the SWNMP which include DFID. DFID has also given a small grant to further the research on the Organic Resource Database with Wye College.

TSBF has also a network of scientists, mainly at Universities in India, in South Asia (SARNet) where research of this type is also in the process of implementation.

Conclusions:

Our brief contained a request for some statement of priorities for the next ten years. Within the field of nutrient management the following five areas seem certain to form part of the research agenda of TSBF and its partners:

1. Refinement and development of the Organic Resource Database and Integrated Nutrient Management Decision Support Systems; extension of the work to a wide range of countries and sites.

2. Adoption, dissemination and extrapolation of improved practices for integrated nutrient management.

3. Research on the residual effects of integrated nutrient management practices; management of low quality resources

4. Linkages between nutrient management and land management.

5. Strategic research on the biological basis of soil fertility; development of a biotechnological capacity in soil fertility management.

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New approaches to research and development in Africa: the case of integrated nutrient management

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Introduction

The agricultural sector in sub-Saharan Africa (SSA), still the largest contributor to the Gross National Product, faces a number of major challenges in the near future: it must produce sufficient food for the growing rural and urban population, increase efficiency and productivity to meet the increased competition in a global, liberalised world market, and maintain the natural resource base to secure production potential for future generations. So far the picture is far from bright: food production per capita is declining (FAO, 1995a), cereal and meat produced more efficiently in Europe, USA and Asia have started to push African products from the market (Holtzman and Kulibaba, 1992), and productivity of the natural resource basis is declining. In particular water is becoming an increasingly scarce production factor (FAO, 1996), fertile top soil is being eroded and soil nutrients are mined (Stoorvogel and Smaling, 1990).

However, underneath this global sketch, a much more diverse and resilient picture emerges. The agricultural sector in Africa is characterised by a large diversity in farming systems in different agro-climatical and socioeconomic environments. Farm households have developed different strategies to cope with the various and changing environments and have increased productivity by developing indigenous technologies or by adopting (and adapting) available appropriate technology developed by the public and private research sector. Several cases have been reported where farmers have managed to increase productivity, income levels and conservation of the national resource base (Richards, 1985; Reijntjes *et al.*, 1992; Reij *et al.*,1996; Wiggins, 1995).

Soil nutrient depletion is generally regarded as one of the most serious constraints to agricultural production in SSA. The average N, P and K balances for SSA in the period 1982-84 were estimated at -22, -2.5 and -15 kg ha^{-1} yr^{-1} respectively (Stoorvogel *et al.*, 1993). In the mountainous and densely populated countries in East and Southern Africa higher nutrient depletion rates occur than in the drier countries in West Africa. This is caused by high values of nutrients in harvested products and erosion, and also by the higher inherent fertility of the soils in East and Southern Africa. In Sahelian soils, there is relatively little left to be lost. At a smaller scale, even more variation between districts, catchments, farming systems and activities within farming systems are observed. Soil fertility research and a state-of-the-art review of integrated nutrient management (INM) technologies and their degree of adoption in Africa have been published, among others, by Mokwunye *et al.*, (1996) for West-Africa, and by Braun *et al.*, (1997) for Ethiopia, Kenya, Uganda and Madagascar. These reviews were commissioned by IFDC and ICRAF (African Highlands Initiative) respectively.

What are the main causes of these negative nutrient balances? An increasing population needs more food and cash and the total agricultural production has increased over the past 20 years, although not sufficiently to meet the growing demand (Table 1). Increasing fertiliser consumption rates in the 1970's and 1980's were a major contributing factor to this increase in production. However, with the large-scale implementation of Structural Adjustment Policies (SAPS) the value-cost ratio of fertilisers at farm level reduced dramatically, resulting in stagnation in fertiliser consumption. Farm households found it increasingly difficult to sufficiently replenish exported nutrients from the farm and expanded cultivation to more fragile soil types. The farm households are often well aware of the short-and long-term effects and have developed or adopted relevant alternative technologies, but their options for addressing this situation are limited due to factors like poor property rights, immediate cash needs, high risks, shortage of labour, limited infrastructure and insecure agricultural output markets.

Table 1. Agricultural production (total and per capita), population and fertiliser consumption in SSA in the period 1975 - 1995 (FAO Agrostat; Gerner and Harris, 1993; FAO, 1995b)

Year	Agricultural production index (1979-81 = 100)	Population (million)	Per capita food production index (1979-81 = 100)	Fertiliser consumption (1000 ton)
1975	97	318	112	693
1980	100	367	100	959
1985	114	425	98	1220
1990	132	498	98	1230
1995	137	564	96	1279

In order to effectively address the problem of soil fertility decline in the current socio-economic environment, maximum use has to be made of the existing variability in conditions, options and current farming practices between regions, farming systems, farms and even within farms. No blanket recommendations are required but a search for a carefully targeted mixture of optimum use of external inputs and maximum use of locally available, renewable and recyclable resources is needed; in other words, development of Integrated Nutrient Management (INM) programmes. The development of appropriate policy instruments which facilitate the adoption and implementation of INM practices must be an integrated part of such a programme. The development of such an INM programme requires a thorough knowledge of existing farm management and farm household decision making. This led to the development of the NUTrient MONitoring programme (NUTMON), first described by Smaling and Fresco (1993), and further elaborated by Smaling *et al.*, (1996). This paper introduces the concept of a nutrient monitoring programme as an approach to develop appropriate INM practices. The diagnostic phase of this approach is illustrated in a case study in Kenya, where diagnostic results are used to formulate a participatory technology development programme.

NUTMON history, present and future

NUTMON was not developed overnight. It is a more or less logical follow-up of earlier research and development efforts in the field of soil fertility and its management in Africa. An overview is given below, starting with the colonial days, and focused on Kenya.

- Colonial days

Mainly on-station research on crop response to different nutrients (often published in East African Agric. and Forestry Journal, and in the Journal of Agric. Science (Cambridge), as well as Agronomie Tropicale and Cahiers ORSTOM; reviews by Rothamsted International, Rockefeller Foundation, ICRAF, IFDC, CIRAD, Mokwunye *et al.*, 1996; Braun *et al.*, 1997.)

- 196Os-1990s

FAO Fertiliser Trials: rate-response trials on farms, mainly researcher-managed; only climate/soil specific since the late 1980s.

- 1985-1995

Fertiliser Use Recommendation Project Kenya (area-specific fertilizer recommendations, valid for well-defined soil-climate groupings; funded by Germany and EU; Smaling and van de Weg, 1990; Smaling *et al.*, 1992; Transition in 1993 into the currently active Fertiliser Extension Project (funded by Germany).

- NUTrient BALance studies (1989-1993)

Sub-Saharan Africa study on NPK balances (FAO-initiated); Stoorvogel *et al.*,1993; Nutrient balance 1983: N -22 P -2,5 K -15 kg/ha,yr.
Desk study on Kisii District, Kenya, NPK balances (DLO-initiated); Smaling *et al.*, 1993; Nutrient balance 1990: N - 1 12 P -3 K - 70 kg/ha,yr.

- NUTMON-Phase 1 (1994-1997)

Pilot study in three districts in Kenya on 26 farms in three districts; funded by Rockefeller Foundation; Special issue of Agriculture, Ecosystems and Environment on INM studies in Africa (1998); Nutrient balance: 1996: N -71 P +3 K -9 kg/ha,yr.

- NUTMON-Phase 11 (1996-1999)

VARINUTS (Kenya, Burkino Faso): spatial and temporal variation of nutrient stocks and flows and INM; calculation of leaching, upsaling; Smaling and Braun (1996); EU-funded LEINUTS (Kenya, Uganda): can farmers make a living out of INM based on low external input agriculture?
EU-funded.
NUTSAL: INM development in Semi-Arid Lands of Kenya; EU-funded.
NUTSEO: Kenyan-Dutch think-tank on INM; DLO-funded.

- NUTMON-Phase III (1998-..)

NUTNET: concerted action with NARS and NGOs in 6 African countries, UK and The Netherlands; DGIS-funded.
NUTFARMER: learning platforms for INM; submitted to EU for funding.
ERONUTS: role of erosion in nutrient balance; submitted to Ecoregional Fund for funding

Nutrient monitoring for development of integrated nutrient management

One of the major underlying principles of the NUTMON approach is to develop a comprehensive multidisciplinary methodology which targets at different actors in the process of managing natural resources in general and plant nutrients in particular. For the NUTMON monitoring approach the following specific objectives have been formulated:

(i) To determine the perceptions of farm households to soil nutrient depletion and related constraints and potentials.
(ii) To acquire a comprehensive knowledge of a farm system and the dynamic functionality of its internal and external nutrient flows in a spatial and temporal context.
(iii) To quantify nutrient flows and balances of existing farming systems at different spatial scales.
(iv) To quantify the economic performance of existing farming systems at different spatial scales.
(v) To identify, on-farm test and evaluate with stakeholders relevant INM- technology options.
(vi) To identify and evaluate with stakeholders relevant policy instruments enabling INM-technology adoption.
(vii) To formulate development scenarios, research priorities and policy advice to reduce soil nutrient depletion.

Farm monitoring takes place at plot and farm household level, since most of the decisions concerning nutrient management are taken at that level. Influences of processes at lower scales (for instance factors determining leaching) and higher scales (policy instruments influencing farm management decisions) are studied as well and incorporated in the farm level approach.

Two major phases can be distinguished: diagnosis and analysis of existing farm and nutrient management and participatory INM-technology development. The diagnostic phase aims at analysing the current nutrient management, determining the magnitude and major sources of nutrient depletion, analysing the economic performance, creating farm households awareness of nutrient management aspects and, jointly with the farm households, arriving at a research and development agenda. The results of this diagnostic phase are the basis for planning and implementation of mainly on-farm trials relating to Integrated Nutrient Management. Farmers, extensionists, NGO-staff and researchers are fully involved in this planning and implementation process and therefore both existing indigenous knowledge and scientific knowledge (or a combination of the two) can be incorporated in this process of technology development. In the past two years, extensive experience has been gained in the development of the methodology for the comprehensive diagnostic phase and the tools developed are presented hereafter.

To classify the complex and heterogeneous situation at district scales, various Land Use Zones (LUZ) are identified using geographical maps, Agro-Ecological Zone maps (AEZ), land use maps, satellite images and expert consultation. Participatory Rural Appraisals (PRA) are conducted thereafter to identify different farming systems and major constraints in farm management. Based upon these PRA, farm types within each LUZ are defined

The soil nutrient stock of a farm is defined as the total amount of nutrients present in the top 30 cm of the soil profile. Both nutrients in the organic matter fraction, nutrients adsorbed to the solid phase and nutrients in solution are regarded as part of the stock. Between 10 and 25 samples per farm are taken depending on the farm size and heterogeneity of soils and cropping patterns.

In order to enable quantification of nutrient flows in a wide range of different farming systems, the farm is conceptualized as five types of units where nutrients are stocked: primary production units (crop production, pasture, farmyard etc.), secondary production units (animals), redistribution units (compost heap, stable), stock (grains, crop residues) and the farm household. Between those stock units three basic types of nutrient flows are distinguished: flows into the farm, flows out of the farm and internal flows (Table 2).

Table 2. Nutrient flows at farm level

IN flows		**OUT flows**		**Internal flows**	
IN1	Mineral fertilisers	OUT1	Farm products sold	FL1	Animal feeds
IN2	Organic inputs	OUT2	Other organic products	FL2	Household waste
IN3	Atmospheric deposition	OUT3	Leaching	FL3	Crop residues
IN4	Biological nitrogen fixation	OUT4	Gaseous losses	FL4	Grazing of vegetation
IN5	Sedimentation	OUT5	Runoff and erosion	FL5	Animal manure
IN6	Subsoil exploitation	OUT6	Human faeces	FL6	Farm products to household

The separate nutrient flows are quantified in various ways (van den Bosch *et al.,* 1998). Firstly, flows directly related to farm management are quantified by monthly discussions with the farmers on inputs to and outputs from the units (chemical and organic fertiliser use, harvest of crop and animal products, redistribution of crop residues and farmyard manure). N, P, and K contents of the 'nutrient carriers' are determined in the laboratory, prices are determined directly in the interview or collected during a separate survey (opportunity costs). Secondly, flows that cannot easily be quantified by the farmer (like quantity of outside grazing and manure excretion of different types of animals) are estimated by means of a simple submodel. A third group of flows (atmospheric deposition, gaseous losses, leaching and erosion) are quantified fully on the basis of off-site knowledge using transfer functions.

Based largely upon the same input and output flows economic performance indicators are calculated at farm and 'activity' level using a spreadsheet calculation module (Table 3).

The results of the models are discussed and validated in a workshop between the participating farm households, extensionists and research staff. This participatory diagnosis is then followed by discussions focusing on formulating priorities for testing and developing INM-technologies in the different farm types and Land Use Zones. Based upon the results of these meetings a participatory on-farm research programme is formulated and implemented.

Table 3. Farm household characteristics and economic performance indicators

Farm household characteristics
- number of persons
- consumer units/labour units
- farm size/R-value
- total Tropical Livestock Units (TLU)
- total invested capital
- land/consumer ratio and land/worker ratio
- capital - consumer, worker and land ratio

Activity level
- gross margin primary production units
- gross margin secondary production units
- total cash flow primary production units
- total cash flow secondary production units

Farm household level
- net farm income
- family earnings
- farm net cash flow
- household net cash flow
- monthly household net cash flow
- monthly labour (family/hired)
- monthly labour (crop/livestock/general/off-farm/household)

Performance criteria
- crop production intensity and returns
- livestock production intensity and returns
- farm level returns to land, capital and labour
- non-farm income
- family earnings

NUTMON-Phase 1: Preliminary results from pilot studies

Results of the diagnostic phase of the NUTMON approach are presented for 26 farms in three districts in Kenya over a 12 month period in 1995/1996, covering two growing seasons. The major characteristics of the three districts are presented in Table 4.

Table 4. Characteristics of the studied districts in Kenya

Characteristics	*Kisii*	*Kakamega*	*Embu*
Altitude (metre a.s.l.)	1500-2200	1250-2000	760-2070
Soil	nitisols, pheaozem well drained,deep	ferrasols, acrisols depleted	andosols, nitisols cambisols, ferrasols
First rains	February-June	March-June	March-July
Second rains	July-December	July-November	October-November
Annual precipitation (mm/yr)	1200-2100	1650-1800	640-2000
Annual temperatures (^{0}C)	16-21	18-23	16-23
Population density (persons/m^2)	800	650	130
Population growth (%/yr)	3.8	2.8	3.7

The total nutrient balances at farm household level amounted to -71 kg N, +3 kg P and -9 kg K ha^{-1} yr^{-1} with large variations between farms (van den Bosch *et al.*, 1998). Differences between district averages were observed for N and K, but were not statistically significant. On average 21 kg ha^{-1} yr^{-1} of N was imported through fertilisers, but on 46% of the farms less than 5 kg ha^{-1} yr^{-1} of N was applied through fertilisers. The most striking was the negligible import of organic fertiliser: of the 26 farms, 25 did not import any organic fertilisers at all. However, import of nutrients through organic feeds and through extensive grazing makes IN2 higher than IN1. Outflow of N through crop products (OUT1) averaged at 11 kg ha^{-1} yr^{-1}, while outflow of N through livestock products (OUT2) was relatively low at 6 kg ha^{-1} yr^{-1} with no significant differences between the districts. Although not significant, the partial balance for Kisii appears to be lower as compared to the balances for Kakamega and Embu. Leaching (OUT3) was the highest at 53 kg N ha^{-1} yr^{-1}, while gaseous losses (OUT4) were calculated at 24 kg N ha^{-1} yr^{-1}. Losses through erosion were estimated at 28 kg N, 10 kg P and 33 kg K ha^{-1} yr^{-1}.

The average Net Farm Income (gross farm income minus total farm costs) amounts to US$ 1490 per farm per year (Table 5), with large variations between farms. Between the districts no significant differences were observed. Crop and livestock activities contribute equally to the net farm income, although in Kakamega the share of livestock activities was significantly higher compared to the other districts. The average economic performance of the farm activities is satisfactory when looking at the realised returns to land and to family labour, which are above the district averages for land rent (US$ 55 ha^{-1} yr^{-1}) and wages of unskilled labour (US$ 1.5 day^{-1}) respectively. However, there was extremely large variation among the farms and 46% of the farms in the sample realised lower returns than these averages.

The average annual farm net cash flow (total farm receipts minus total farm payments) amounted to US$ 675, with no significant differences between the districts. Crop and livestock activities contributed equally to the total farm cash income, although in Kakamega, a significantly higher contribution of livestock was observed. The average market orientation of the farms, expressed in the percentage of the total revenues of crop and livestock outputs sold, was 45% varying from complete subsistence (0%) to almost fully market oriented (95%). The selected farms in Kakamega district appeared more subsistence oriented, although the difference was not statistically significant. On average, 770 labour days were used for farm activities, equivalent to two full-time persons, of which around 15% of this labour was hired with, again, large variation between farms. The labour intensity of crop activities in Kisii and Embu was considerably higher than in the more extensive farming systems in Kakamega. Labour intensity in livestock between the districts was comparable.

Table 5. Economic performance indicators at farm level for 3 districts in Kenya

	District			**Total**
	Kisii (n=6)	**Kakamega** (n=8)	**Embu** (n=12)	
Net farm income (US$ $farm^{-1}$)	1435	1655	1420	1490
Farm net cash flow (US$ $farm^{-1}$)	490	525	855	675
Returns to land (US$ ha^{-1})	-200	110	235	90
Returns to family labour (US$ ha^{-1})	1.4	2.4	2.5	2.2
Share crops in income (%)	49	19	68	49
Market orientation (%)	48	30	55	45
Labour intensity crops (days ha^{-1})	258	176	281	244
Labour intensity livestock (days TLU^{-1})	65	63	68	66
Farm Income Sustainability Quotient	0.53	0.60	0.80	0.68

One of the available options to estimate the sustainability of a farming system is to relate the costs of replacement of mined nutrients against replacement costs, to the net farm income. The Farmers Income Sustainability Quotient (FISQ) can then be defined as follows: FISQ = 1 minus value of nutrient deficit/net farm income (van der Pol, 1993). Over all the farms, an average Farm Income Sustainability Quotient (FISQ) of 0.68 was found, indicating that 32% of the net farm income was based upon nutrient mining. At district level for Kisii, Kakamega and Embu FISQ was 0.53, 0.60 and 0.80respectively, with the differences not statistically different. These figures indicate that given the current prices of fertilisers and agricultural products, replacement of the depleted nutrients would reduce net farm income by around 30%. In addition it is estimated that currently 54% of the farms in the sample realise income levels from farm activities which are below the poverty line (De Jager *et al.*, 1998). This leads to the conclusion that in the current socio-economic environment for a large portion of the households, agricultural production takes place in an agronomically and economically unsustainable way and that off-farm income is essential for large groups of small-scale farm households to achieve economic viability. Creating changes in the socio-economic environment will therefore be just as important as developing Integrated Nutrient Management technologies to attain more sustainable agricultural systems.

It appears that the market orientation can be used as a discriminating factor for nutrient balances and farm management aspects. Three groups of market orientation are distinguished: < 33%, 33-66% and >66% of the gross revenues sold. Subsistence oriented farms (<33%) have a significantly less negative nutrient balance for N and K than market oriented farms (>66%, Table 6). The partial balance for N was positive in all three groups, but the inflow through fertilisers increased with the market orientation. Inflow through organic sources on the other hand decreased with market orientation due to lower numbers of livestock which were kept in zero grazing units (less outside grazing) and fed from on-farm produced napier grass. The market orientation is related to intensification of the farming system: capital and labour intensive production on relatively small cultivated areas. No significant differences were observed between the groups in economic performance and economic sustainability although, logically, the farm net cash flow was higher on the market oriented farms. The FISQ appears to reduce with increased market orientation, although not significantly. The market oriented farms imported comparable amounts of nutrients, although from different sources, but export of nutrients through products and through losses in leaching and erosion were considerably higher. On the subsistence oriented farms, the nutrient balance was relatively positive through concentration of nutrients from grazing land to the cultivated area for arable crops. The sustainability of the system was therefore related to the grazing to arable land ratio; increasing land pressure may lead to a decline of this ratio.

Table 6. Farm management, nutrient balances and economic performance according to market orientation of farms expressed in % of gross returns sold

	Market orientation		
	<33%	33-66%	>66%
N-balance (kg ha^{-1})	-26[a]	-89	-106[b]
P-balance (kg ha^{-1})	-2	5	6
K-balance (kg ha^{-1})	32[b]	-12[b]	-68[a]
Net Farm Income (US$ farm^{-1})	1380	1615	1455
Farm net cash flow (US$ farm^{-1})	182a[a]	764	1236[b]
Farm Income Sustainability Quotient	0.73	0.56	0.62
Cultivated area (ha)	6.7	4.3	1.7
TLU	4.4[b]	4.2[b]	1.5[a]
Zero grazing unit (1=yes/2=no)	2.0[a]	1.5[b]	1.4[b]
Share of livestock in income (%)	61[a]	63[a]	16[b]
N-inflow fertilisers (IN1 in kg ha^{-1})	9[a]	18[a]	45[b]
N-inflow organics (IN2 in kg ha^{-1})	54	21	14
Labour intensity crops (days ha^{-1})	179	226	373
Labour intensity livestock (days ha^{-1})	71	48	91

[a,b] - the mean difference is significant at P=0.05 level

At crop level the returns, gross margins and variable costs of the major cash crops, coffee and tea, were considerably higher than those of the major food crops, maize and maize-beans. Although not statistically significant, food crops tended to have more negative nutrient balances than cash crops.

Higher levels of fertilisers are applied to coffee and tea than on food crops and also the added values realised differed considerably (Table 7). Economic studies of the Fertiliser Use Recommendation Project (FURP) showed that application of fertilisers to food crops was not economical in the short term, and the data showed that this was consistent with actual farm practices. However, the low fertilisation levels in food crops result in high replacement cost levels. For coffee and tea the expenditure needed to replace the mined nutrients amounted to 20-30% of the gross returns, while for food crops it was at least 70-80% of the returns. Based on these data a gross margin sustainability quotient (GMSQ) can be calculated as follows: 1 - nutrient deficit value at replacement costs / gross margin. For cash crops, this GMSQ is significantly higher than for food crops.

Table 7. Added value, actual and needed fertilization expenditures and sustainability quotient for major crops in 3 districts in Kenya

	Crops			
	Coffee	**Tea**	**Maize**	**Maize-Beans**
Gross returns (US$ ha^{-1})	1355	620	85	205
Added value (US$ ha^{-1})	1120	475	65	190
Replacement costs (US$ ha^{-1})	40	50	125	130
In % of returns:				
Actual fertilisation expenditures	17	23	23	8
Needed expenditure	20	31	173	70
GM Sustainability Quotient	0.97	0.90	-1.46	0.24

Contrary to crop activities, livestock, just like the remaining identified places for nutrient storage on the farm (manure stock, food stock, farm family and garbage heaps) show, on average, positive nutrient balances (van den Bosch,1998). Three different 'cattle systems' are distinguished: zero-grazing, semi-zero-grazing and extensive grazing systems. No significant differences between the gross margins and nutrient balances of these cattle management systems were found, but the more intensive zero-grazing system tended to realise higher gross margins and more positive nutrient balances than the more extensive systems.

Conclusions

The first experiences with a farm-level multi-disciplinary monitoring approach, although still in development, have proven to contribute to understanding the current farm management systems, to identify the existing diversity in soil fertility management strategies, and to target and prioritise different development options.

The results have shown that the rather alarming values of nutrient mining at national level consist of a heterogenous pattern of nutrient balances and flows in different farming systems and enterprises. It is exactly this heterogeneity which the NUTMON approach will exploit to develop appropriate and tailor-made INM-technologies, which should be geared towards an economically optimum mix of nutrient-adding and nutrient-saving techniques.

From the Kenyan case study presented, it is obvious that INM technology development must be matched with adequate policy instruments to facilitate adoption of these practices at farm level. The NUTMON exercise revealed that current agricultural production is not sustainable both from the viewpoint of nutrient management and economic performance. This implies that for successful adoption of developed INM technologies, favourable socioeconomic conditions for farmers have to be created.

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Constraints of the organic approach to sustainable agriculture

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The HDRA survey

The Henry Doubleday Research Association (HDRA) has recently completed a project to investigate farmers perceptions and attitudes towards 'organic' agriculture in sub-Saharan Africa. Information was obtained through a postal survey of 213 community development groups in 24 countries of sub-Saharan Africa and from field work in Ghana and Kenya. A major area of investigation, particularly in the field work, was farmer perceptions of, and strategies for managing, soil fertility. Both rural and peri-urban farmers in three agroecological zones were interviewed during the field work. The agroecological zones selected in Ghana were the wet evergreen forest zone, the moist semi-deciduous forest zone, and the savannah zone. In Kenya the three agroecological zones selected were the high potential area of the central highlands around Nairobi, the medium potential area in the humid western part of the country, and the low potential area of the semi-arid uplands.

Fertiliser use

Seventy three percent of respondents to the postal survey reported that farmers used fertilisers and only 23% that they did not. From the field work, there was a significant difference ($p<0.001$) in the percentage of farmers using chemical fertilisers in the three zones surveyed in Kenya with use around Nairobi (86%) being higher than around Kisumu (33%) or Kitui (15%). In the forest zone of Ghana, 43% of farmers used fertiliser of whom 76% applied this to vegetable crops. In the savannah zone of Ghana, 58% of farmers interviewed used fertiliser on the household farm, of whom 84% applied the fertiliser to maize. The percentage of farmers using fertiliser was significantly ($p<0.01$) higher in peri-urban than in rural areas, reflecting the greater intensity and commercialisation of vegetable production closer to the market centres.

Other inputs for maintaining soil fertility

The soil inputs listed in the postal survey questionnaire are shown in Figure 1. Most of the groups (88%) reported the use of a range of combinations of soil inputs by some or most of the farmers. Twelve percent of respondents stated that few/none of the farmers used any of the listed soil inputs. No group reported that most (almost all) or some (about half) farmers used all of the organic soil inputs listed, although several respondents reported that most/ some of the farmers were using five or six of the nine inputs listed.

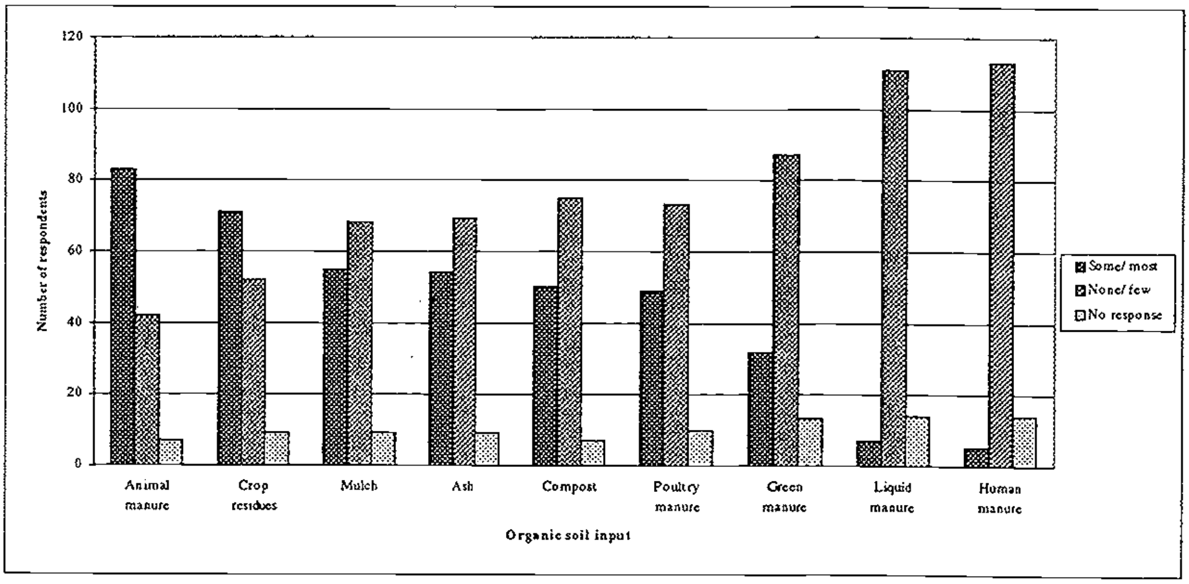

Figure 1. Extent to which organic soil inputs are used by farmers, (postal survey).

Limited funds to buy fertilisers was rated as an important reason for adopting alternative soil management techniques by 64-70% of respondents to the postal survey and was frequently cited for Ghana, Kenya, Malawi, Niger and Uganda. In some cases (23% of respondents in the postal survey) non-availability of fertilisers was also a factor reported to stimulate the use of alternatives. This was also revealed in the Kenyan field survey.

In the postal survey, environmental concerns were rated as important by approximately 40% of the respondents, mainly related to the long term effect of fertilisers on soils. Field work also revealed that in the more intensive farming systems, such as the ones around Nairobi, there have been some experiences of negative impacts of fertilisers. There was a widespread perception that inorganic fertilisers are damaging soil structure and moisture holding capacity and creating an economic dependency on costly inputs in order to maintain yield. Other groups, who have not used fertilisers to a great extent, also have some reservations about artificial fertilisers for environmental reasons. Farmers around Kisumu and Kitui perceive that once you start using fertiliser you have to continue to do so. With the limited cash and supply in such areas this creates feelings of fear and risk.

In contrast, in Ghana, the awareness of potential negative effects of fertiliser on the soil was much lower, the only evidence being found with some farmers in peri-urban Kumasi where fertiliser use is the most intensive, and in the savannah zone of Ghana. In the latter area, of those farmers who were using fertiliser, or who had stopped recently due to the price increase, 50% said soil was not affected, 31% indicated that there was a diminishing return with increasing amounts of fertiliser; and 19% indicated that fertiliser increased weed growth or that its application without rains hardened the soil.

Factors affecting the potential for organic soil fertility strategies

Agroecological zones: Clearly some soil fertility strategies might be expected to be more common in some zones than in others. For example, the extent of manure use depends, at least in part, on livestock numbers and management, which vary with agroecological zone. No clear differences among agroecological zones emerged from the postal survey, but in the field work there were clear differences between the forest and savannah zones in Ghana and between the agroecological zones surveyed in Kenya.

Peri-urban/rural: Farmers in remote areas with poor infrastructure and without access to fertilisers may have few options but to use alternative soil fertility management techniques to achieve sustainable and more productive agriculture. In areas of higher economic potential, farmers may not consider alternatives to fertilisers as viable options. Developed markets may increase the use of fertilisers by the need for continuous intensive cropping of small plots. Also, in general, the more commercially oriented production becomes, the greater the incentive to use, and ability to afford, chemical inputs. There is an alternative view that farmers who live relatively close to urban centres may have access to agro-industrial or urban municipal wastes, offering greater potential for organic soil fertility management.

Farm sub-systems: Important differences also exist within single farms or among distinct holdings of a particular farmer. Many farmers operate a number of enterprises often spatially separated. For example there may be more scope for sustainable soil management in home gardens or plots close to the homestead, than for larger and/or more distant plots where the main cash and field crops are grown.

Land tenure: People's willingness to adopt sustainable agricultural technologies, which require investment in time and/or money and which will provide benefits in the long term, is directly related to land tenure relations. Around Nairobi, where farmers have good access to manure and fertiliser, rented land tends to receive less manure but more fertiliser than owned land. Farmers do not wish to invest their valuable manure for someone else's benefit, since the land could be used by the owner at any time. Also, they need to ensure a rapid return to cover the cost of renting the land.

Financial considerations: There is a link between the degree of commercialisation and the use of inorganic fertilisers, with farmers supplying well-developed markets having the economic incentive and the ability to purchase non-organic inputs. It should not be assumed however, that organic fertilisers are necessarily freely or readily available at relatively low cost. Some organic soil inputs will certainly be from materials recycled on the farm, and it is the objective of organic farming to maximise this. Larger mixed farms may even be self-sufficient for these inputs. However, supplies are rarely adequate on small intensive farms and external sources of fertiliser, whether organic or not, are required. This results in a market for organic fertilisers and composts, in which case organic fertilisers become economic inputs with the same implications as chemical fertilisers for poor farmers.

Gender: Apart from general considerations of the influence of gender on the distribution of land, activities, income and decision making, there are specific aspects relating to the potential for soil fertility strategies. For example, women's access to manure in northern Ghana is limited and socially complex.

Constraints to the adoption of organic techniques

Reasons for non-adoption of organic soil fertility management techniques are shown in Figure 2.

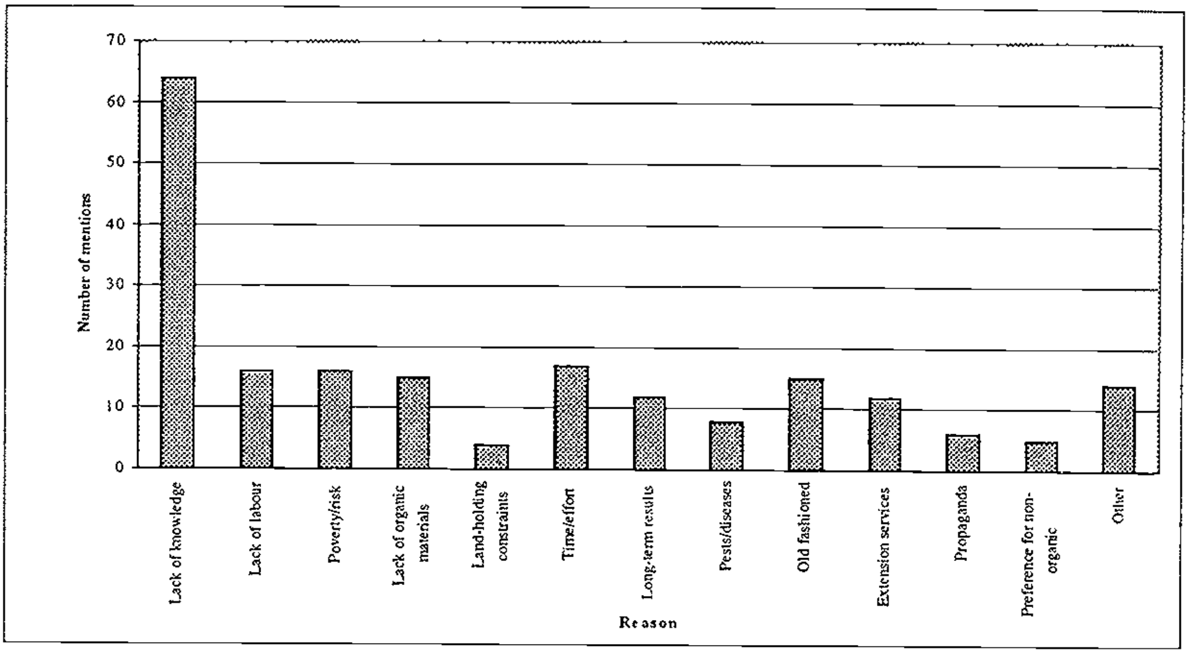

Figure 2. Reasons for non-adoption of organic soil fertility management techniques, (postal survey).

Lack of knowledge/education: It is often assumed that farmers have a comprehensive wealth of indigenous knowledge about soil fertility management. This is often not the case. In fact, this study showed that farmers were often not optimising the natural resources at their disposal. Examples of this are poor manure management and the rather 'accidental' use of organic soil inputs, previously discussed. Furthermore, farmers are often growing new crops or are operating new farming systems of which they have no previous experience.

In the postal survey, by far the most widely cited reason for lack of adoption of 'organic' techniques, mentioned by 63% of those filling in this part of the questionnaire, was the farmers' lack of knowledge or awareness. Many of these responses were phrased in general terms, such as 'they have no idea of these farming methods' (Ghana) or , 'lack of awareness/ignorance' (Nigeria), while others focused more on the lack of knowledge of the benefits of organic inputs.

This is not always the case and, for example, lack of information on composting does not appear to be a major constraint to its adoption in Kenya. Seventy one percent of farmers had received some form of education about composting. This information was obtained from school (37%), extension services or other farmers (23% each), NGOs or other groups (12%), or radio (5%). The promotion and understanding of organic technologies for soil fertility maintenance are generally very low amongst the extension staff. There was also little evidence of NGO work among the random sample of farmers interviewed.

Labour: The most frequently cited constraint to organic soil fertility management was that of labour. This is true in general and for specific organic techniques. For example, in Kenya farmers identified lack of labour as a constraint to the adoption of composting. Organic soil fertility maintenance may involve manure collection and spreading, composting, tree pruning and green manure incorporation. These techniques are likely to require more labour input than either traditional farming or modern high input agriculture. In areas with low ecological potential, the labour requirements tend to be highest and the returns to the investment take longer to be realised. Cash poor farmers who cannot afford to hire labour, and farmers who depend on off-farm work to supplement their farm incomes, may not be able to adopt any agricultural practices which increase the labour burden; particularly if short-term increases in farm productivity are not guaranteed. Many female headed households with migrant male absentees are in this situation.

Risk of failure or lower yields: An underlying theme of poverty as a constraint to the adoption of a wide range of novel techniques for managing soil fertility came through in the postal survey. Phrases, such as 'poverty, lack of funds' were given as reasons for farmers not developing organic techniques, but more common were references to farmers' unwillingness to change to organic inputs because of the fear of failure or the risks involved.

Lack of organic materials: A number of responses cited unavailability of organic materials to be their prime constraint to utilising organic soil inputs. The particular materials mentioned usually included animal manure and crop residues.

Competition for use: Farmers in many areas are faced with a choice of uses for available materials and in countries such as Ethiopia, with a shortage of fuel wood, cow dung is used for fuel. In the savannah zone of Ghana, crop stalks are collected as fuelwood, or used in construction and mat making, particularly in the peri-urban areas. Crop residues are often too valuable as animal feed to be used as fertiliser or for composting. In Uganda, the poultry manure which is available is mixed with brewery waste and used as a cattle feed rather than as a fertiliser.

Cost of organic materials: The cost of organic materials may prevent the poorest farmers from using them. In Kenya, as the farmers' perception of the benefits of manure has increased, so too has the price, particularly as the cost of inorganic fertiliser has risen. The cost of sewage in the Ghana savannah zone also limits the extent of its use. The amount paid to the truck drivers varies considerably and no doubt influences the number of deliveries purchased by farmers.

Transport of organic materials: Some groups also mentioned the inability to transport materials to the fields or around the farm. In the Ghana forest zone, problems related to transport include both the cost of transport of poultry manure to the farm and the general transport of manure around the farm. The distances from the household to the farm are often large and the use of any form of draught power or ownership of implements such as wheelbarrows is non-existent. Also, owing to the bimodal high rainfall pattern paths are easily overgrown making access difficult.

Cultural constraints: There may be an unwillingness to handle waste in many parts of sub-Saharan Africa, particularly human waste. In such cases farming systems cannot be designed to rely on the application of waste for soil fertility, unless such cultural constraints can be overcome. In the Ghana forest zone, considerable social stigma is attached to manure handling since it is often mixed with human excreta and other rubbish. In contrast, in northern Ghana no reservations were expressed about the handling and use of manure or even human sewage.

Aversion to the use of organic soil inputs

Time/effort: Amongst the replies in this survey, there were several that related not so much to the availability of labour *per se*, but to the unwillingness to spend the necessary time. Comments such as 'the practice of organic farming is tedious to undertake' (Ghana), that 'collecting and preparing ingredients needed for organic farming is tedious and time-consuming' (Tanzania).

Long-term results: A lack of 'immediate' results was cited in the postal survey as a reason for not using organic inputs. For example, phrases such as 'it is a long process' were used. It may not be feasible for resource poor farmers, to adopt alternatives to fertilisers unless short term benefits can be realised.

Pests/diseases/weeds: Several replies referred to the problems of increased weeds, pests and diseases. A group in Zambia reported that 'farmers believe that animal manure encourages weeds'. It is a common perception in Kenya that manure from animals fed infected residues can carry diseases such as tomato and potato blight. A respondent from Ghana said that, 'compost heaps attract very difficult pests and animals to the project', while in Kenya, 'some claim the methods, like application of mulch, harbour pests which destroy crops'.

Old-fashioned: Adverse comparisons of organic inputs with the preferred inorganic ones were also expressed in phrases which indicated that the former are considered to be 'old-fashioned'.

Attraction of fertilisers

From some respondents in the postal survey it was clear that there was a significant satisfaction with, and preference for, the use of fertilisers on the basis of their good and rapid results and ease of use, or the need to use fertilisers because of soil exhaustion or lack of fallow. No doubt the increased use of fertiliser has also been influenced by active promotion. The role of government agriculture departments and more particularly the extension services in choice of farming techniques was given as a reason for use of fertilisers by 13% of postal respondents. Comments such as 'Government extension service advocates modern farming methods' (Malawi) were common, and several replies referred to the fact that the extension services were trained to use, and therefore promote, chemically-based methods. Groups in Malawi specifically mentioned that the Government encourages the use of chemicals in their radio agricultural programmes. One respondent felt that organic farming was actually 'against government policy' (Tanzania). Two replies also referred to the promotion, through subsidy, of fertilisers and pesticides prior to structural adjustment programmes, which has contributed to farmers becoming used to non-organic methods over a long period of time.

Conclusion

The use of artificial fertilisers is widespread among farmers in sub-Saharan Africa and only a minority of farmers practise unimproved traditional subsistence agriculture. The potential to increase productivity by either traditional soil fertility management techniques, or by chemical fertilisers alone is limited. Therefore, improved organic techniques need to be introduced alongside fertilisers. Amongst the farmers surveyed there was very little evidence of adoption of improved soil fertility management techniques. Although isolated techniques are sometimes practised, there is a lack of integrated soil fertility management exploiting a range of techniques to maximise the benefits of locally available natural resources.

Considerable potential exists for better utilisation of organic materials, for example by minimising nutrient losses during storage and handling of manures and by exploiting the organic fraction from the urban waste stream in urban and peri-urban farming systems. However, organic soil fertility management techniques are subject to a wide range of practical, cultural and economic constraints.

The use and appropriateness of chemical fertilisers or alternative soil fertility management strategies, and the balance between them depend upon a range of interrelated factors. These include the degree of intensification of the farming system, climate, cropping system, land size and ownership, proximity to urban markets, financial constraints, gender, culture, education, degree of exposure to chemical fertilisers versus organic management techniques, and availability of alternatives to fertilisers. Organic techniques are not universally applicable at the whole farm level and consideration needs to be given to sub-systems. Thus, there are likely to be quite different requirements for techniques for vegetables, cash crops, perennial tree crops and staple food crops. Furthermore, the appropriateness of particular soil fertility management strategies is likely to differ according to spatial characteristics of farms.

Goodbye to hunger; the adoption, diffusion and impact of organic farming in rural Kenya[1]

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> *"Practising organic farming is like saying good-bye to hunger"*
> (Lower Mwea farmer)

Aims

The above comment is just one perception of organic farming and this report is concerned with farmers' perceptions. It aims to understand their experience of a remarkable transformation that has been taking place in parts of rural Kenya since 1993, the year in which the teaching of organic farming took off. The change is important, representing perhaps the last stage in the intensification of agriculture that has accompanied the relentless growth of population in rural Kenya throughout this century. Is this change sustainable? Are there factors propelling it forward and others acting as constraints? What has been the impact upon the farmers involved? Answers will be sought through the views of the farmers themselves.

Methodology

In structuring the study, it is recognised that there are five components involved in the adoption and diffusion of organic farming:

- *Teachers*: teaching NGOs constitute an important part of the farmers' experience and attitudes will have been shaped accordingly.
- *Self-Help Groups* (SHGs): organised for teaching purposes, they constitute another important dimension of the farmers' experience.
- *Adoption of Techniques*: a package of techniques has been taught, some of which have been adopted and others not.
- *Diffusion*: organic farming has spread at three different scales: within farms, between farms and across regions.
- *Impact*: upon the farmer's standard of living can be judged in relation to food supply, experience of hunger, crop sales (especially vegetables), diet and health.

These five "fields" defined the structure of the fieldwork, the field report and this workshop paper. Within each, positive and negative factors may be detected.

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[1] (Based upon a report of the same title, published (No. 12 of 1997, 206 pp) by the Association for Better Land Husbandry, PO Box 39042, Nairobi, Kenya).

The sample design for the fieldwork (July-August 1996), produced 23 groups, usually divided into two or three sub-groups, and 68 individuals distributed across three ecological zones (High, Medium and Low Potential) and from the spheres of 9 teaching NGOs. The latter facilitated the selection of groups and the establishment of contact in the field. The individuals included taught adopters, spontaneous adopters, drop-outs and non-adopters in or near those groups. The method of enquiry for farmers was a pragmatic blend of PRA and conventional questionnaire. Group Secretaries were separately interviewed, as also were the teaching staff of the nine NGOs.

NGOs: The nine NGOs involved in the teaching of organic farming were:

Western Province: Manor House Agricultural College (MHAC), Kitale; HOPE, Naitiri; Organic Matter Management Network (OMMN), Kakamega; YMCA, Busia; CARE, Siaya
Eastern Province: Kenya Institute of Organic Farming (KIOF), Machakos.
Central Province: Othaya Child Family Programme (OCFP), Othaya; Church Province of Kenya (CPK) (= the Anglican Church), Wanguru, Kirinyaga Diocese; OMMN, Kerugoya.

These NGOs differ considerably in terms of size and scale of operations. HOPE, Naitiri operate out of half a hut and have a localised impact whereas Manor House is a residential college with strong regional impact in Western Province and KIOF, from its substantial base outside Nairobi, will contract to teach groups anywhere in Kenya. These three were created specifically to teach organic farming but others such as CPK, YMCA and OCFP integrated organic farming into pre-existing development strategies. Indeed OCFP do no teaching, contracting out to KIOF. In fact, KIOF and Manor House have been directly or indirectly involved in almost all of the teaching. The former taught all of the Othaya and Machakos groups, undertook the initial teaching in the two OMMN areas and greatly influenced CPK in Wanguru. HOPE and YMCA Busia have been much influenced by Manor House (MHAC).

Two aspects of the teaching by NGOs are important. In terms of content there is some difference between MHAC and KIOF. Both have the composted Double-Dug Bed as the central technique but the latter preach "hard-line" organic farming, requiring the immediate cessation of all chemical inputs, whether as fertilisers or pesticides. MHAC, who prefer the term "bio-intensive agriculture", take a more relaxed view of the use of chemicals and tolerate a gentle transition to wholly organic farming. OMMN share this view.

More significant are differences in the delivery of the teaching. KIOF give farmers 1 week courses in their villages, followed by three months of follow-up by a resident college student. MHAC bring the farmers to their campus for 1 week residential courses and then provide follow-up by staff visits to the villages. Unfortunately both of these institutions have recently suffered funding problems which have reduced the efficiency of follow-up. In contrast, YMCA Busia and HOPE both enjoy the advantages inherent in small size. YMCA has put 4 extension officers out in the villages, turning their homes (farms) into "resource centres" which provide permanent follow-up. HOPE are able to provide permanent follow-up from their one base, given the small area involved. Quite different from all of these are CPK and OMMN Kakamega both of which have placed heavy emphasis upon farmer to farmer teaching, the former through a system of "contact farmers" and the latter developing a pool of farmer-teachers who undertake teaching to groups over a wide area.

With regard to the farmers' perceptions of the NGOs, negative comments far outweighed the positive, although almost none related to the quality of the teaching itself. The principal problem is lack of follow-up. Farmers complained of a sense of isolation leading to frustration both in attempting to resolve, on their own, problems encountered with the new techniques as well as in generating motivation. This frustration is a significant cause of drop-outs. Most of the criticism was aimed at KIOF, notwithstanding their standard three month secondments, for there was no long-term follow-up offered after that. This reflects the nation-wide scale of KIOF's operations, for permanent follow-up would be impossibly expensive. As noted above, the small NGOs such as YMCA Busia and HOPE Naitiri have no such problems. They know their farmers and are praised for the frequency of follow-up contact.

Another important criticism of NGOs is that they fail to plan holistically. It is argued by farmers that there is little point in persuading farmers to adopt organic farming if the wider environment makes adoption pointless. Why teach organic farming in Machakos if the water supply is incapable of sustaining it? And why teach farmers to grow radishes and lettuces for sale in Kakamega if there is no market?

Self-help groups

Groups play a key role if only because all NGOs require farmers to form into groups for teaching purposes. But there is more to it than that. Groups have to be legally registered, after which they may elect committees, hold democratic meetings, set subscriptions and open bank accounts. Some are strong financially whereas others have virtually no financial dimension. This can be directly relevant to organic farming because savings can be invested in equipment, seeds or livestock which that farming requires. Groups may also use savings to rent or purchase group land, which usually is collectively worked and used both to demonstrate and implement organic farming. Any income is fed back into group savings. Another impressive financial system organised by most groups is "Merry-Go-Round" whose aim is to generate savings for individuals. The group meets at the house of an individual member, each contributing an agreed cash sum to the householder. Groups decide how this money is to be spent by the individual and often use it to strengthen organic farming, for example by insisting that is dedicated to the purchase of a goat to boost manure supply.

Beyond the formal dimension there are informal practices which are unquantifiable but crucial. For example, organic farming involves hard labour which can be daunting for women farmers. Many groups alleviate this problem by helping each other with this work. They also help when a member falls sick. Although there can be tensions within groups, sometimes causing drop-outs, it is rare for groups to fail completely and the overwhelming response was that group membership is beneficial in relation to the learning of organic farming, instilling a sense of security and improving motivation.

The adoption of organic farming techniques

Characteristics of adopters: With one exception, no clear pattern emerged from the survey concerning the distinguishing characteristics of adopters. Most farmers believed that age, family size, soil quality, wealth and level of commercialisation of the farm had no influence on propensity to adopt. The one exception was gender, there being general agreement that women were more likely to adopt than men. Up to a point this confirms the stereotype of organic farming as being women's work in the kitchen gardens whilst the men look after the main cereal fields or work off-farm. However 24% of the 424 group members for whom information was available were men and in three groups men actually outnumbered women, so that their role is not negligible. Moreover many women are also involved in the larger farm.

Perceptions of organic farming techniques: Organic farming, as taught by NGOs, consists of a "package" of techniques. Two are absolutely central, the Double-Dug Bed (DDB) and Compost, with the latter being an integral component of the former, although of course being usable separately. If farmers were unimpressed by these two techniques, then organic farming would have no hope of achieving sustainability. Two other techniques are closely related to the composted DDB in that they are used to control.pests and boost output from the vegetables grown on them: natural pesticides and liquid manure respectively. The remaining techniques in the "package" have nothing to do with DDBs. They include other forms of bed (Mandala Gardens, Nine Maize Seeds in a Hole, Trenches), Zero Grazing, Poultry, Agro-Forestry and Bee-keeping.

Farmers were asked which of these techniques were most popular and why, making positive and negative comments as appropriate. The results of two separate surveys (of individuals and of groups) were highly encouraging in that they agreed that DDBs and Compost were in a class of their own in terms of popularity, with well over four-fifths of farmers responding favourably. Indeed, well over a half had these two techniques as either their favourite or second most popular technique. This is not to say that there were no negative comments but positive comments exceeded negative ones by a ratio of 3.2 to 1 in the case of DDBs and 1.9 to 1 for compost, whereas for all other techniques negative comments exceeded positive. Indeed no other techniques came anywhere near DDBs and compost in terms of popularity although the other two core techniques (Natural Pesticides and Liquid Manure) were viewed positively by between a half and two-thirds of the two samples. The "peripheral" organic farming techniques attracted only a lukewarm response being rated favourably by well under a fifth of the sample.

The reasons for the popularity of the core techniques are important. Made to a standard size of 7m x 1.5m, the construction of Double-Dug Beds requires considerable effort (prompting negative comment) involving the removal of top soil, breaking up of the sub-soil, especially any hard pan, and the generous application of compost to the top soil which is duly replaced. Nonetheless the advantages are perceived as overwhelming. Some relate to the ease of weeding, watering and harvesting of beds of this size but the critical advantage relates to the higher yields that they will produce. Vegetables can be planted at greater densities than normal, growing more rapidly and producing larger, better-tasting leaves (kales and spinach). In part these follow from the deeper digging, allowing root systems to develop but what is particularly appreciated is the ability of DDBs to conserve water, thus allowing production to continue through the two dry seasons. This yields a considerable cash premium (see below).

Perceptions of compost are equally positive, again notwithstanding the labour involved: in the gathering of raw materials (a huge difficulty in Othaya where vegetation is in short supply); in constructing pits (in sub-humid areas); and in turning the compost every three weeks (three times). Farmers appreciate the effect of compost upon both soil structure and fertility, frequently comparing it favourably with chemical fertilisers. They claim that the effect of the latter rarely lasts for more than a season, compared with up to three years for compost. Add to this the escalating cost of chemical fertiliser and the popularity of compost is assured. These highly positive responses to the composted Double-Dug Bed allow us to be optimistic about the future of organic farming, a conclusion that will be reinforced when the impact upon standard of living is considered.

Of the other core techniques, liquid manure is seen as effective, if not always necessary, but the cost of equipment and high water requirement deter adoption for many. In contrast, natural pesticides are critical since their function is most definitely essential: protection against crop loss. They are viewed by farmers with ambivalence, enthusiasm being mixed with frustration. Although negative comments substantially exceeded positive, they are still the third most popular technique and for one SHG (Obukosia, YMCA Busia) they were the favourite. Chemical pesticides, like chemical fertilisers, are now hugely expensive and this is perceived as a major advantage for the natural product. Farmers are also aware of the health risks with chemicals, sometimes cynically so, using them on tomatoes for urban markets whilst refusing to apply them to production for the household. However, the problem with natural pesticides is their patchy record in terms of effectiveness. There is general agreement that the recommended wash made from Mexican marigolds and hot peppers is reasonably effective against aphids and leaf-cutters on vegetables but there is much frustration that they have no effective natural counter to blight on tomatoes (an important cash crop on DDBs) and potatoes. They are therefore forced to use chemical pesticides if they wish to market these products. This failure prompted much negative comment as also did confusion over dosages. Solution of the blight problem and more effective follow-up could thus make a major impact upon small farm economies.

Of the other techniques, the negative reaction to zero grazing was disappointing, given the importance of boma manure in compost making. High initial capital costs for the unit and for grade cattle were largely to blame. The various forms of sunken bed (including Nine Maize Seeds in a Hole and trenches) were regarded as too demanding on labour, although some key innovators in sub-humid Machakos are experimenting with them. Poultry are not popular because of damage inflicted on DDBs but, with Bee-keeping, hold out a prospect of significant incomes and dietary improvement in the future.

Diffusion of organic farming

The extent to which organic farming has spread within farms and between farms is an obvious indicator of the success or failure of the new technology.

Diffusion within farms: One of the surprising results of the survey is the conclusion that it is by no means the case that organic farming is constrained to the kitchen gardens, as the stereotype would have it. There has been great interest amongst farmers in expanding to the rest of the farm, where maize production is universally the dominant land use. This is a diffusion of compost application and not Double-Dug Beds, the compost replacing the use of chemical fertilisers. Progress varies greatly by group and there are some where there has been no diffusion at all from the kitchen gardens (*e.g.* Obukosia in Busia), whereas in others (*e.g.* Kivandini in Machakos; Sibale in Busia; Mwimathia (excluding tea land) in Othaya) most members have reached the limits of expansion. In a sample of 45 individual farmers, 26 had extended composting into the main farm lands, 17 of these covering the whole area available. Most of the 19 who had made no progress were applying boma manure with chemical fertilisers. This suggests that a majority of adopters are sufficiently impressed with organic farming to want to expand its use to the limits.

Diffusion between farms: "Between Farm" diffusion may take place either by adopters actively promoting organic farming amongst neighbours or by other farmers spontaneously seeking to copy adopters, usually asking their help. Obviously the latter will only happen if the results on the adopters land are impressive. The survey suggests that both processes operate but that spontaneous adoption is probably four times as common as deliberate promotion. This is an encouraging result. Equally encouraging is the rate at which this diffusion is taking place, a best estimate suggesting that, allowing for a drop-out rate of 20%, 100 farmers taught by an NGO would have expanded in three years to 185 by "between farm" diffusion, *i.e.* almost doubling.

The spatial extent of NGO teaching: Interviews with NGOs allowed a crude estimate to be made of the progress of diffusion at the regional and even national scale. How far are we up the adoption S-curve? The answer seems to be, in the words of the field officer at OMMN Kakamega, that adopters represent "a drop in the ocean." The KIOF field officer in Machakos District indicated that, although there had been a district-wide awareness campaign, teaching had been concentrated almost entirely in just one of the 4 divisions (Kalama) in the district. In Kalama an estimated 10% of farmers would have been taught organic farming, with another 20% being added as a result of farmer to farmer teaching. For the District as a whole, therefore, the percentage practising was probably less than 10%. Othaya reported a similar achievement in the one division (out of 4) in which teaching had been concentrated in Nyeri district. If these results are typical of areas where teaching has been most intense, then it may safely be concluded that, overall in Kenya, adopters must represent well under 10% of total farmers. These are early days.

The impact of organic farming

Food security: For millions of small farmers in Africa the most basic issue of all is survival, and famine is not always a fear that is in the background. It can be a reality and has been in Machakos in 1996-97. An attempt was therefore made to measure the impact of organic farming upon food security, farmers being asked whether they were self-sufficient in maize before adopting and after; and what strategies they used to acquire food. The results were sobering but encouraging. Before adopting, only 40 out of 178 families (22%) were producing enough maize on their farms. The commonest strategy employed to acquire food, especially in Kakamega and Busia, was the hiring out of their labour on farms, followed by the sale of crops such as tea or coffee in regions where this was possible, notably Othaya and Kerugoya. Urban remittances have always been important in Machakos. After adopting, the proportion self-sufficient in maize more than doubled to 48% as a result of composting maize, an impressive achievement although a matter of concern that over a half are still short. Strategies, however, have changed as a result of adopting organic farming, especially in Kakamega and Busia where hiring out has almost disappeared and the sale of vegetables has become the commonest strategy for generating income to buy maize. But how successful have these strategies been? Do they generate enough income to allow the complete elimination of hunger?

Hunger: The answer to the above question, regrettably, is negative although the situation has greatly improved. Prior to adopting, the situation was appalling. 57% of the sample of 180 experienced hunger each year, indicating that strategies such as hiring out labour were largely unsuccessful, only the sales of tea in Othaya and coffee in Kerugoya and Upper Mwea allowing majorities in these areas to be hunger-free. Large majorities experienced hunger where such sales were not possible (Kakamega, Busia and Machakos). After adopting, the proportion still experiencing hunger plummeted from 57% down to 24%, a spectacular improvement, although daunting that a quarter of families in the survey still suffer hunger in a normal year. The improvement has been notably dramatic in Kakamega and Busia where vegetable sales have replaced hiring out as the survival strategy. Large majorities are now hunger-free. Sub-humid Machakos, however, is a special case for, although normally a majority are hunger-free, there may be years (*e.g.* 1996) in which the main rains fail, in which case the whole population will be in difficulty.

Self-sufficency in vegetables: Prior to the introduction of organic farming, kitchen gardens scarcely existed and such vegetables as were grown (usually a few cowpeas) were interplanted with maize on the main farmlands. They were grown, like the maize, with chemical fertilisers and generally died off during the dry seasons. "Startling" is not too dramatic a word to use in relation to the impact that organic farming has had upon vegetable self-sufficiency. From a situation before adoption in which 85% of the sample had to buy vegetables (inevitably in very small quantities), organic farming has allowed a massive 77% to become sellers. It is difficult to exaggerate the significance of this remarkable turnaround. Prior to 1993 vegetables were a drain on the resources of 85% of families alongside expenditures on maize and school fees. Now 77% of families have an inflow of cash from this source and this can be used to buy maize (the need for which has itself been reduced as result of increased yields from composting) and contribute to school fees and other household needs.

The output of the double-dug bed: Given the significance of vegetable sales as noted above, it is worth attempting to quantify the income-generating potential of the DDB. The survey indicated that the median number of DDBs operated by farmers was 7, with the range running from 2 to 25 and that 3 or 4 DDBs would generate enough for family consumption. Although many vegetables (and maize) are grown, much the commonest is sukuma wiki (kales) which have the advantage of producing fresh leaves over many months. As context for the income figures that follow, it may be helpful to know that a bag of maize (90 kgs) in the hungry seasons may cost 1200 KSh (approx 80KSh per £)and that an average family would need 12 bags a year. A grade cow might cost 25,000 KSh; and school fees for a primary school 2000 KSh pa and secondary school 20,000 KSh pa.

What income then could be produced from, say 4 DDBs under kales if all the output was sold? The answer seems to be that an average yield would be between ¼ and ½ of a 90kg bag per week per DDB and that the income would depend entirely upon whether production could be extended into the dry seasons. One Kakamega farmer succeeded in producing ¼ bag per week through one dry season in 1994/95 (December-March) and was delighted to get prices of around 300 KSh per bag in those months. This compared with 50-70 KSh during the following main rains (April-June 1995). She failed to keep production going during the July-September dry season but then received 150 KSh per bag during the short rains from October-November 1995. Her gross income from 4 DDBs can be estimated at 5,550 KSh, nearly enough to buy 5 bags of maize at peak prices or put three children to primary school. The income, however, was well short of that needed to buy a grade cow or send a child to secondary school.

A number of conclusions follow from the above example. If she could have produced through the second dry season, the extra two months at 300 KSh per bag would have brought in another 2,400 KSh boosting total income to almost 8,000 KSh . On the other hand, farmers who only produce during the three months of April-June at 60 KSh per bag will generate gross incomes of only 720 KSh and there were examples from the survey in this position . At the other extreme, given that a quarter of farmers had 11 or more DDBs, if 8 of 11 were producing for market, then gross incomes would be double those of the Kakamega farmer viz over 11,000 KSh; and 16,000 if producing through both dry seasons. Finally it needs to be noted that, if anything, these dry season prices are underestimates, some reporting 700 KSh and even 1000 KSh per bag. The premium from double-digging may be even greater than that indicated, and of course there is no immediate limit to the number of beds that a farmer can construct.

Diet and health

Formerly the rural diet was almost totally dominated by maize, usually prepared as "*ugali*", a maize dough eaten with gravy. Nutritional diseases, such as kwashiorkor, were common and it is significant that at least five of the NGOs became involved with organic farming because it was seen as a potential solution to poverty and related nutritional problems. At Othaya one of the first actions of the officer who initiated organic farming, was to construct a large kitchen garden for the local orphanage. There followed a dramatic improvement in the children's health, hospital visits dropping from 5 per day to a few cases per month. Elsewhere, several groups refer to the elimination of kwashiorkor and the survey recorded a flood of positive comment on the attractiveness of the diet now that onions, carrots, spinach, kales, cabbages, tomatoes and peppers are available.

Conclusion

There seems every justification for reaching an optimistic conclusion concerning the achievements and future prospects of organic farming. If a planning team in 1992 had set out to boost maize self-sufficiency from 22% to 48%, reduce experience of hunger from 57% to 24% and the number of farmers having to purchase vegetables from 85% to 11%, the aim would have been dismissed as utopian. Yet this is what has happened to the survey farmers in three short years. The composted Double-Dug Bed has been a huge success and their owners are immensely proud of them and the lush vegetables that they produce. Not only are they seeking to improve all available land but neighbours are so impressed by what they see that they are spontaneously adopting in large numbers.

Certainly the survey pin-pointed problems. The number of drop-outs is significant. Some groups have effectively excluded the poor in order to boost group savings. The lack of follow-up by some NGOs has threatened the sustainability of organic farming in some groups. Difficulties with techniques, such as natural pesticides, have discouraged some. And failure to create the necessary external environmental conditions (water supplies and markets) has rendered the exercise pointless for some. Nonetheless the achievements have been impressive, representing a massive intensification of production on small farms. If sustained, this would create a stable platform for long-term rural development, although it has to be said that uncontrolled population growth and land fragmentation might undo all the good work within a generation.

Participatory approaches to soil fertility management: some experiences from Africa

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Introduction

The nutrient cycles of small-scale African farms are immensely complex, involving multiple pools and flows, each mediated by a range of socio-economic processes. The management of soil fertility in such settings requires diverse approaches, responsive to ecological conditions and socio-economic circumstances. Conventional approaches to soil fertility management often start and finish with the technical question: do nutrient inputs balance nutrient outputs? This is undoubtedly an important issue, but often there are many other unasked questions which require attention. These include those relating to scale and management, to social, economic and cultural processes mediating nutrient cycles, and to the historical dynamics of environmental change (Scoones and Toulmin, in press; Scoones, 1997).

This paper draws on recent field experiences in three African countries - Mali, Ethiopia and Zimbabwe[1] - where a more participatory approach to investigating and acting upon soil management issues has been developed and tested. Such an approach tries to go beyond the conventional framing of the soil management question in purely technical terms, and draws in a variety of other perspectives more rooted in the farmers' own understanding of system dynamics. Rather than proceeding directly to interventions based on the scientists' recommendations, a more adaptive exploration and monitoring of technology options is explored. Such an approach provides an alternative to the linear, transfer-of-technology mode so characteristic of conventional research and development systems, by offering a more analytical and interactive way of analysing complex and diverse agroecosystems and a more participatory approach to involving multiple stakeholders in decisions about technology options for sustainable agriculture.

Agroecosystem complexity and diversity

In contrast to the stylised models of farm-level nutrient cycles we see in soil ecology text books or the simplistic assumptions embedded in the design of many agronomic experiments, real farms are highly complex and diverse. For example, a resource flow diagram (available from the author) drawn by Hidotu Sankura, a farmer from Wolayta, Southerm Ethiopia, shows how complex connections exist both within the farm, particularly the flows of resources (manures, household waste, ash, etc) from the homestead to the garden plots close to the

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[1] This paper draws on experiences arising from the project 'Dynamics of Soil Fertility Management in Savanna Systems in Africa' (EC-DGXII TS3-CT94-0329), coordinated by the Drylands Programme of the International Institute for Environment and Development and involving research partners in Zimbabwe (Bright Mombeshora, Farming Systems Research Unit, Department of Research and Specialist Services, Ministry of Agriculture, Box CY594, Harare), Mali (Ibrahim Dembele, ESPGRN, BP 12, Niono) and Ethiopia (Ejigu Jonfa, Farmers' Research Project of FARM-Africa, Box 5746, Addis Ababa) and the Netherlands (Arnoud Budelman/Toon Defoer, the Royal Dutch Tropical Institute, KIT, Amsterdam).

home, and beyond the farm, notably the flows to and from the market place. Such complexity requires a sensitive approach to analysis and modelling which captures key features.

Of course there is no problem with abstraction and simplification for modelling or experimental purposes, if such abstraction relates to some key aspects of a farm system. But how do modellers or experimental scientists who rarely visit a real farmer's field know what is key and important? Too often assumptions are made about scale, landscape position, the relative importance of particular flows or pools or the dynamics of the system which, in turn, influence the nature of the analysis and so the results. Asking the right question is the most important part of good science. And good applied science must ask the right question in relation to the likely users. This is almost so obvious that it should not need saying. But sadly the experience over many decades has been that too often scientists have asked the wrong questions and with rarely any consideration of real users. The existence of inappropriate fertiliser recommendations, after years of investment in trials of all sorts, in country after country is witness to such a process of inappropriate research.

With the challenge of sustainability on everyone's lips these days, the need to understand farm-level complexity and diversity and local users' perspectives is even more acute than before. Finding ways that different farmers, with different views about soils and their ecology, can engage with conventional science and scientists is a major challenge for the future. This challenge has been the focus of our work over the last few years, the experience of which is discussed in the following sections.

Farmers and scientists working together

The debate about farmer participation in agricultural research is now well established (cf. Farrington and Martin, 1988; Chambers *et al.*. 1989; van Veldhuizen *et al.*, 1997). But in our eagerness to embrace the rhetoric of participation, the rationale for such partnerships is sometimes overlooked: why is it that working together makes sense? For the applied scientist there are many obvious reasons why a close relationship with users is essential. These include the need to understand the problem from users' perspectives; the need to frame questions and design experiments in ways that yield useable results; and the need to develop outputs with clear uptake pathways. The benefits of participation for farmers is, however, less obvious. Sometimes the designs and methods used may be useful in farmers' own research; sometimes new materials or technologies are offered for testing; and sometimes a genuinely new and useful output results. But all too often farmers are enlisted in scientists' projects and benefits from such engagement are not mutually shared.

However, experience from Mali, Ethiopia and Zimbabwe shows that, if sensitively designed, an interactive learning approach can provide benefits for both farmers and scientists, resulting in genuine collaborative research and action. It appears that questions surrounding soil management are particularly well suited to this type of learning partnership. Why is this? Two factors are important: the importance of the issue, and the complexity, difficulty or observability of the problem. Soils are clearly important to farmers, and fertility is often a key constraint in areas where farming has been continuous for some time. Also, soil fertility is a complex and challenging problem which is often not immediately apparent, involving the interaction of soil water, organic matter, macro and micro-nutrients, with high levels of variability over time and space. With the farmers' recognition of the importance of the issue, as part of their wider concern for the farm system and their own livelihoods, and the scientists' ability to analyse specific elements of soil complexity, a potential complementarity is apparent.

In a different context, Bentley (1994) has argued that the two axes of importance and observability are key (Table 1).

Table 1. The importance of importance and observability: some examples of soil issues (adapted from Bentley, 1994).

Low importance/high observability	*High importance/high observability*
Surface crusting	Gulley erosion Soil macro-fauna (termites, earthworms)
Low importance/low observability	*High importance/low observability*
Radionuclide concentrations Fossil deposits	Micro and macro nutrient deficiencies Rill/sheet erosion

Clearly the priorities for research and action must be those which are seen as important to some broader goal, such as livelihood creation, agricultural productivity or sustainability. Those issues which are observable and important in this sense can often be dealt with by farmers alone, perhaps with limited external support. In the soils context, this category might include some aspects of soil erosion control, such as gulley reclamation (cf. Reij *et al.*, 1996). But those issues which are important yet difficult to observe are perhaps the most challenging, and where farmers and scientists can join together in fruitful partnership. In the soils context, soil fertility and nutrient management issues clearly fall into this category. In situations where everyone recognises the importance of the issue, yet observation is problematic, new methods to encourage farmer analysis may be required. Work in Ethiopia, Mali and Zimbabwe has shown how soil fertility management questions raised by farmers offer a range of opportunities for such interaction and joint learning. Some of these experiences are discussed below.

Adaptive experimentation and joint learning: experiences from Africa

Participatory learning and action approaches have begun to be developed over the last 3-4 years in collaboration with a number of research partners across the three countries' research sites, including farmers' groups, NGOs and government research and extension organisations. At the local level a process of diagnosis, experimentation and monitoring has taken place involving inputs from individual farmers and scientists. From small beginnings, this has started to have wider impacts through the development of new networks and the creation of new organisational relationships to encourage on-going learning and action. The basic approach, moving from diagnostic work to action research, is summarised below (see also Defoer *et al.*, 1996; Mavedzenge *et al.*, in press).

From diagnosis....

To start with, joint analysis of the agroecosystem is focused on the assessment of a variety of issues, including historical change in the environment and farming system; changing inputs and outputs at farm level; analysis of differences in soil management practice by wealth, age and gender; and influences of external economic and political factors. This phase of the work makes use of a variety of participatory rural appraisal methods, as well as more conventional historical and anthropological approaches. Each contribute to an overall assessment of the area, discussed at each stage with village participants.

As part of such diagnostic studies, farmers may analyse the flows of resources on their farms using bioresource flow diagrams (see Figure 1), indicating the sources and sinks for different fertility sources (cf. Lightfoot *et al.*, 1992). This analysis focuses attention on areas for improvement. Each of the flows in a bioresource diagram is mediated by a variety of socio-economic factors. For example, market access or commodity prices affect some flows, while property rights and tenure affect access to and control over other resources. An analysis of such conditioning factors provides important information on the wider factors affecting the possibilities for farm-level action, and sets the more technical bioresource modelling analysis in a broader context.

.... to action research

Once different socio-economic, gender and age categories of farmers have analysed their bioresource flows, a number of problem areas may be defined. These may be more generally felt by farmers in the area or they may be specific to a particular farm. The next challenge is to explore the array of potential solutions through searching for alternative intervention options. The process of searching for new technology or management options often does not have to go far afield. Indeed, as people come together to discuss the results of the diagnostic studies, and tours of farms are arranged, a range of different locally generated ideas become apparent. In many cases these became the initial basis for testing and experimentation. In addition, links with other sources of innovation can be made through visits to farmer innovators in other areas or to nearby research stations or experimental sites.

With a range of alternative options to test, farmers and researchers then design an experimental and monitoring programme together. Table 2 lists a selection of the wide range of options explored by farmers across the sites in the three countries.

Table 2. Options tested and monitored by farmers and researchers (Sources: FARM Africa, 1996; Defoer *et al.*,1996; IER, 1996; FSRU, 1996; Mavedzenge *et al.*, in press).

Ethiopia	**Mali**	**Zimbabwe**
Crop residue management on main outfields. Increasing manure and urine use efficiency, including reducing leaching/ volatilisation losses, bulking, improving application procedures. Low labour input Composting techniques. Inorganic fertiliser application procedures to increase use efficiency and reduce costs.	Soil amendment experiments: compost, inorganic fertiliser, rock phosphate, cattle manure, cotton stalks and other residues. Improved fallow systems, including litter and residue incorporation. Composting systems to increase recycling and nitrogen availability. Transportation of manure/ compost (carts, changing location of cattle pens, compost pits).	Soil amendment experiments for improving sandy soils: leaf litter compost, ash, cattle manure, termitaria, inorganic fertiliser (and combinations). Improving sodic soils: river sand, termitaria, drainage lines, gypsum (and combinations). Composting pit systems and compost application rates.

Two parallel approaches to experimentation have emerged. Farmer research groups have often taken forward more conventional experimental testing of options using simple designs and matrix scoring techniques for evaluation. For example, in Zimbabwe 20 groups have formed in the Chivi district study area during the period from 1993 to 1997. Their average size is 7.7, with two-thirds being women members, and they are usually based on existing groupings often around extended kin networks and residence clusters (Mudhara *et al.*, 1996; Mavedzenge *et al.*, in press). Similarly in Mali and Ethiopia, individual farmers and groups have undertaken experimental work in collaboration with researchers on their fields.

In parallel, a smaller group of farmers have engaged in a more detailed monitoring of the bioresource flows on their farms. Initially between 9 and 15 farmers across three categories of soil management capacity (highly correlated with resource access/wealth) in each of the two sites per country, volunteered (although this number has since increased in some sites). Making use of farm-specific diagrams, they have analysed and monitored changes between years, assessing the degree to which the interventions they make (such as shifting applications to different sites, increasing recycling through composting or mulching etc.) are judged, according to their own criteria, to be successful. Alongside these plot-based experiments and processes of farm-level monitoring, researchers have also collected data on soil changes, nutrient balances or yield levels (see, for example, Eyasu, Elias 1996 and Defoer *et al.*, 1996 for Ethiopia and southern Mali respectively).

A key stage in any joint research of this sort is for the different research actors to come together and to discuss and interpret results. Feedback sessions are usually held during the harvest period when results are evident in people's fields and later in the dry season when a more complete assessment is possible and when planning for the next season is undertaken.

Following analysis and discussion, the cycle of learning and action must repeat itself. In order to sustain the enthusiasm and energy that results in new insights and successful technological innovation and adaptation, new ideas and sources of innovation must be continually injected into the learning system. Thus, with new issues identified, the process of search, supply, intervention and monitoring must be repeated through an annual cycle. Across the three countries such a cycle has been continuous for a number of years now. There have been ups and downs, but, in some sites, there is growing evidence that, given limited external support, a sustained interactive approach to learning and experimentation can emerge.

New challenges

Once such a cycle of action research has been established, new challenges inevitably arise. During this process a number of questions have been faced in all three countries.

> First, how can new approaches to translation and communication be devised which allow the languages and concepts of western and local sciences to be discussed?
>
> Second, how can issues of power be addressed in the context of new research and action relationships? How can new forms of professionalism be engendered amongst researchers and extensionists working in new ways with farmers?
>
> Third, how can a process of action, reflection and learning be sustained, and, indeed, scaled-up beyond case study farms? How can new organisational forms be encouraged which continue to support these new relationships and networks?

Such questions are, of course, not new. They are central to the large challenges posed by a more farmer-centred approach to on-farm research (cf. Scoones and Thompson, 1994). How has the work in Ethiopia, Mali and Zimbabwe responded to such challenges? Not surprisingly, given the different settings and circumstances, diverse responses have resulted. But some general themes have emerged.

For example, issues of translation and communication are being explored through the development of visualisation techniques based on a range of participatory rural appraisal methods. Resource flow diagram and ranking techniques, in particular, are easily taken up by farmers and provide some direct links to scientific analysis. A resource guide, based on the experiences of the projects so far, is in preparation, aimed at providing an appropriate methods tool-kit for field-level research and extension workers (Budelman, in prep.).

Questions of power and professional attitudes are, of course, more difficult to tackle, yet are central to any transformation of the research and extension approach. For instance, in

Zimbabwe each year, during farmer-run feedback workshops, research and extension professionals are invited as participants by farmer research groups (Mavedzenge *et al.,* in press). Such 'reversals' (cf. Chambers, 1993) can have a powerful effect on outlooks and attitudes. However, if such shifts are not reinforced by longer term changes in formal training or incentive structures, then 'normal professionalism' is inevitably sustained. It will not be a surprise that this larger challenge remains an issue in all countries.

Finally, there is the question of scaling up. Experience across all three countries shows that a participatory approach to soil fertility management offers new insights and the basis for a potentially productive partnership between farmers and researchers. But these experiences have been at a small scale, involving relatively few farmers in detailed farm-level monitoring and a limited number of farmer research groups in plot-level experimentation. Can this apparently successful experience spread, especially given the limited, and often decreasing, capacity of government departments for research and extension? This remains an open question. To some extent there has been a natural spread when farmers groups have spontaneously formed and demanded that they be involved in the research. But even these new groups are reliant, to some degree, on external support. For really effective scaling up, there remain many challenges of going beyond a limited project setting and institutionalising such approaches within government and extension services, not least ones centred on financial resources. Perhaps the greatest opportunity lies in the networks and organisations of farmers themselves (cf. Ashby and Sperling, 1994), which, given the right support in terms of training and organisational strengthening, may, in the longer term, form the basis for a demand-led and participatory approach to soil management, and draw in scientists and other professionals on their own terms.

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Nutrient Management in Rice-Wheat Cropping Systems and Yield Decline

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The rice-wheat cropping system (RWCS), which involves growing rice and wheat crops on the same piece of land in difference seasons, has emerged as a major production system in the Indo-Gangetic Plains (IGP). It is currently being practiced on about 10 million ha of prime agricultural lands in India. The productivity of rice and wheat crops and of the system increased significantly following the introduction of Green Revolution technologies mainly due to the adoption of high yielding varieties tailored to respond to fertiliser use, enhanced irrigation, and greater area cultivated. Productivity gains however, have not been uniform across the region and productivity growth seems to have reached a plateau in intensively cultivated areas in north-western parts of the IGP. The reasons for yield stagnation and decline are not fully understood; they are not the same across agro-ecoregions. Nutrient management is the major issue to be addressed to understand the reasons for the decline in yields. Fortunately several soil fertility experiments were set up in the region in the early seventies with a view to examining the long-term effects of different combinations of fertilisers, chiefly N.P.K and organic fertilisers, and sometimes Zn, S and B.

Yield trend analysis

Yield decline evidence may come from several sources including agricultural statistics, on-farm surveys and long-term soil fertility experiments (LTSFEs). For meaningful conclusions it is necessary to consider both yield and the factors affecting productivity. In spite of several limitations, the results of LTSFEs permit the following broad conclusions:

- Sustainability of the RWCS is best ensured through integrated use of chemical fertilizers and of organics.
- There is no evidence of yield decline at the level of farmers' fields.
- There is a decline in rice productivity with high levels of nutrient input or in soils which have a history of high nutrient use or high initial soil fertility (eg. Tarai soils). Rice yields in alkali soils following reclamation measures were high initially years decreased gradually. Yields of the following wheat crops were low initially but improved with each passing season.
- Evidence of yield decline in LTSFEs indicates the location specific nature of decline in many cases. In Punjab, yield decline was evident only at high yield levels (> 10t/ha/yr). In Bihar, Zn and B deficiencies in calcareous soils and S deficiency in heavy-textured soils appeared as the major causes for observed declines. In UP where Mollisols predominate, the decline was due to Zn deficiency. No decline was observed in West Bengal, possibly because the soils are young alluvium.

- In most cases the available data sets were difficult to interpret because of 'noise' due to seasonal variations in weather, decline in yield potential of cultivars, change of cultivar; emergence of micro-nutrient deficiencies, varying levels of biotic and abiotic stresses and variations in seeding dates etc. For delineating the extrapolation domains of the LTSFEs and 'prognosis of hot spots' there is a need to develop information management systems in a GIS framework. There is also a need for crop simulation modeling techniques to reduce the noise and to facilitate the scaling of the long-term yield data.

Nutrient balances

- Nutrient balance studies help with understanding the changes in soil productivity due to changes in the amounts and availability of nutrients. Data from LTSFEs collated for many sites indicate that when forest soils of high initial organic matter content (Mollisols of Pantnagar) were used for cropping the soil organic matter content was reduced by about 42-67% in a period of 20 years both with and without applications of NPK fertiliser.
- Application of fertiliser P and K in accordance with soil test-based recommendations sustained the availability of P and K but addition of N fertilisers, with or without FYM failed to restore the availability of soil N to its initial status.
- In soils of low initial organic matter content such as the Inceptisols of Ludhiana, cropping with the addition of NPK fertilisers at 180, 30, and 30 kg ha^{-1} to rice and 180, 60, and 30 kg ha^{-1} to wheat were able to maintain or even slightly raise the soil organic matter content, available NPK levels and to build-up the P stocks. This was also true for Zn. Soil K balance was invariably highly negative due to large crop removals even when K was applied in the recommended doses. However, crop responses to applied K were infrequent. Exports of food grains from the 'surplus' regions caused permanent loss of nutrients from the ecosystems.

Secondary and micro-nutrients

Most of soils in the IGP are calcareous and zinc deficiency is quite common. In experiments, Zn was applied regularly but all other secondary and micronutrients have a negative balance. Sulphur and manganese are becoming increasingly deficient due to increasing use of S-free fertilisers. Iron deficiency in the initial stages of rice growth (rice nurseries in alkali soils) is often seen. There is a need to budget secondary and micronutrients in rice-wheat systems. Boron deficiency is now emerging in the northern Bihar plains.

Nutrient use-efficiency

Enhancing the efficiency of nutrient use is a cornerstone of all research efforts to optimise crop yields and minimise adverse environmental efforts. However, most past studies have shown that fertiliser use efficiency seldom exceeds 30-35% for N, 15-30% for P, and 3-

6% for Zn. The LTSFEs at Pusa and Barrackpore indicated that the efficiency of fertiliser N varied from 26% to 44%, of P from 6% to 23% and of K from 69% to 100%. Efficiency was generally highest at the initial level of nutrient application. At Pusa, recovery of nutrients applied to wheat was 42% N, 12% P, and 156% K for the initial amounts of 50, 30, and 20 kg ha^{-1} N, P_2O_5, and K_2 respectively and 26% N, 16% P and 96% K for the subsequent dose of 50, 30 and 20 kg ha^{-1} N, P_2O_5 and K_2O. For rice the recovery estimates were 52% N, 9% P, and 21% K, and 32% N, 13% P and 80% K for the subsequent dose of NPK. The available data did not permit analysis of changes in nutrient use-efficiency among soils or over time, or the effect of various biotic and abiotic factors in influencing the use efficiency of nutrients. In general, the results suggest higher N uptake in wheat than in rice. Nitrogen response was increased due to reduced soil N supply under some situations. In the rice-wheat system, P recovery was 23-30% with no clear trend over the years. Recovery of K in the rice-wheat system is high (>75%) but precise values need to be calculated and reported. There is a need to calculate the following efficiencies in LTSFEs:

Agronomic efficiency: kg grains/kg applied nutrients.
Recovery efficiency: kg nutrients absorbed/kg nutrients applied.
Physiological efficiency : kg nutrients in grains/kg of nutrients absorbed.

It is essential that all aspects of nutrient use-efficiency are considered especially the interactions of varying nutrient and moisture supplies and the quality of irrigation water. Ground water is fairly high in the IGP and may contain residual alkalinity affecting N losses. Effects of biotic and abiotic factors in influencing nutrient use-efficiency need to be considered when evaluating results from LTSFEs.

Changes in soil organic matter (SOM)

Evidence from several studies points out that high sustainable yields are possible only through combined application of chemical fertilisers and organic manures. In general, SOM content of soils of the Indo-Gangetic Plains is low. In soils of the sub-Himalayan region, SOM declines from an initially high level and stabilises at a modest level (<1.5%). In salt-affected (alkali), sandy, and low fertility soils there is a tendency for the organic matter content to increase and stabilise. These are also the soils which have initial low SOM. Rice-wheat cropping results in a decline of SOM which is maintained only by regular incorporation of green or farmyard manures. Sustainability of the rice-wheat production system crucially depends upon regular inputs of organics to supplement and/or substitute fertiliser N. When organic matter application is discontinued the incidence of micro - and secondary nutrient deficiency also increases. Application of organics while improving soil fertility and infiltration rates, increases the energy requirements for puddling operations and the irrigation water needs of the rice crop. The trade-off issues may not be the same for all agro-ecosystems in terms of groundwater recharge and the development of groundwater.

Soil testing

Soil testing aids decisions on the use of fertilisers. Soil test methods have been used mainly for P and K. Soil test values have been correlated with yields of rice and wheat crops grown under two divergent field conditions. However, some methods have been developed to estimate the potentially useful fraction of N in soils. Methods have also been developed to measure the potentially useful micro - and secondary nutrient reserves in soils. In general, the alkaline permanganate method commonly used to assess soil nitrogen does not adequately evaluate nutrient needs of the cropping system. It often digests a higher proportion of the total soil organic N pool which is susceptible to mineralisation than in a cropping system, particularly rice. The contribution of soil N to the nutrition of the current crop in soils with low organic matter is small. The amount of useful N over a crop season usually depends on the small fraction of organic matter supplied in recent additions of organic manure and other plant residues. A knowledge of recent cropping and manuring is therefore important in computing crop needs for fertiliser N. There is a need to standardise the method against methods that employ milder oxidizing agents. The existing test appears more suitable for wheat than for rice.

Existing soil test methods for P, K, and Zn availability were generally satisfactory. However, in our efforts to improve the existing methods, the phyto-availability test proposed by IRRI scientists needs to be examined. This method involves equilibrating capsules containing both cation and anion exchange resins, with soil slurry for 1-7 days and allows calculation of the rates at which different nutrients in the soil become available to plant roots. The resin capsules are assumed to simulate plant roots as they act as a sink for both the cationic and anionic forms of nutrients. Plants being good indicators of soil nutrient status, there is a need to increasingly adopt tissue analysis techniques to diagnose hidden deficiencies and to improve fertiliser use recommendations. The turbidimetric method for determining the sulphur content of soils needs improvement.

The role of legumes

Inclusion of legumes in a cropping system and green manuring have been practised by farmers for a long time to economise on N and for other benefits. Growing green manure crops, however, does entail costs in their cultivation and incorporation into the fields and may have to be grown at the expense of another crop. When fertilisers became available at moderate cost, N input was considered cheaper than growing green manure crops. With increasing fertiliser N costs, the need to improve the organic matter content of soils is essential for sustained high productivity and stability. Green manuring in a sequence is a healthy practice, and where feasible, this practice should be encouraged as it increases the availability of micro-nutrients and contributes an equivalent of about 60 kg N ha^{-1}. Screening of *Sesbania* cultivars suited to different conditions with fast-growing habits and better bacteria-host plant relations is crucial and is being considered for intense research efforts.

Effects on environmental quality

No substantial information has been generated in the LTSFEs on the effect of the rice-wheat system on environmental quality. However, information from other sources points to the following adverse effects:

- Production of the greenhouse gas, methane, and some toxic substances, (e.g., H_2S) when the soil remains submerged for prolonged periods and crop residues are incorporated. It has been suggested that biogas technology needs to be promoted because apart from providing cooking gas to farm households, methane emissions will be smaller with sludge applications to land than when raw organic materials are applied.
- Leaching of NO_3 - N from the upper soil layers, where most fertilisers are applied, to the water table causes pollution of groundwater. Factors that enhance leaching of NO_3-N are excessive use of nitrogenous fertilisers and/or imbalanced use of nutrients leading to inefficient use of applied N with concomitant losses through leaching.
- In areas using machine harvesters, most farmers burn crop residues to enable timely field preparation for seeding/planting the subsequent crop. Burning crop residues causes air pollution and a significant increase in respiratory problems during the season among the local population. Recycling the residues without adequate measures to hasten decomposition could cause decline in productivity.

Interaction of tillage and crop establishment with integrated nutrient management strategies

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A major factor for achieving high yields of wheat, or for that matter any crop, is timely planting and good plant stands. In South Asia, wheat is grown in the winter, *rabi* season in multiple, sequential cropping patterns following other crops. The harvest of these previous crops like rice, cotton, sugarcane and others often interfere with the timely planting of wheat. Long turnaround times (the time from harvest of one crop and the planting of the next) as a result of poor soil conditions (too wet, too dry or poor soil structure in fine textured soils) or constraints of power can also delay wheat planting. Data from many regional experiments show that delays in wheat planting result in a linear decrease in yield potential in the range of 1.0 to 1.5 % loss ha^{-1} d^{-1} when planting occurs after November. Late planting not only results in lower yield potential, but also reduces the efficiency of applied inputs. Nitrogen response surfaces are much flatter in late-planted plots compared to plots planted at the optimal time.

The Rice-Wheat Consortium for the Indo-Gangetic Flood Plains and Himalayan Mid-Hills was set-up to address the issues of increasing production of these two important cereals in a sustainable way[1]. The regional technical committee of this consortium identified tillage and crop establishment (TCE), integrated nutrient management (INM), water management and crop protection as 4 important research themes. Variety, socio-economic and policy issues were also highlighted as important, but these additional themes are embedded in the other four themes and so were not listed as independent issues. Leadership on TCE issues was given to CIMMYT and we have focused our efforts with the national programs on identifying zero- and reduced tillage options for timely establishment of wheat. This not only increases yield potential but also reduces the cost of production, fuel costs, wear and tear of tractors and increases input efficiency.

The objective of zero- and reduced tillage research is to reduce the turnaround time and get wheat planted closer to the optimum date. Research over the past decade in the rice-wheat areas of South Asia, both on-farm and on-station has identified the following tillage options for this problem:

1. Surface seeding of wheat onto unploughed soil either before or just after rice harvest. The key to this system is maintaining proper soil moisture at seeding and during initial root extension. This system is particularly relevant on fine textured, poorly drained soils, where planting is delayed because of excess moisture. It is also relevant for small farmers since no equipment or power source is needed for the operation. It does create

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[1] The consortium consists of members from the four national programs of Bangladesh, India, Nepal and Pakistan. The major IARC members are IRRI, CIMMYT and ICRISAT (convening centre) although IIMI, IBSRAM and IFPRI have participated. Other centers are welcome and Cornell are presently active participants.

problems for management of nutrients, both inorganic and organic, since fertiliser cannot be incorporated into the soil.

2. Sowing of wheat into unploughed soil using an inverted-T coulter or double disk openers. This is mainly used where 4-wheel tractors are available. This practice is gaining popularity in India and Pakistan in fields where rice stubble is not too much of a problem. Local artisans are producing this equipment at costs within the budgets of farmers and it is gaining popularity. If the seed drills for this technology do not have fertilizer bins, application of fertiliser becomes an issue. Application of organics also poses a problem for incorporation.

3. Combine harvesting is becoming popular in parts of India and Pakistan. In this situation, loose straw left by the combine creates clogging problems with the drill described in 2 above. In this situation, special trash drills with disk openers need to be developed. Another option would be to place a straw chopper in the combine, so the straw can be chopped and distributed evenly on the soil. This would give an additional benefit of mulching and help to maintain good soil moisture. This would have interesting implications for fertiliser efficiency and organic matter cycling.

4. Another option is to prepare the soil and plant in one operation. This reduced tillage option utilises a shallow rotovator ahead of a seed drill, followed by a roller. A two- or four-wheel tractor can power this machinery. The introduction of two wheel, Chinese tractors in Bangladesh, Nepal and eastern India will be particularly relevant for small farmers who are finding that keeping bullocks for ploughing is becoming excessively expensive. These 2-wheel tractors can also be hooked up to other implements for threshing, pumping, reaping, deep plowing and transport. This option causes the least problem with fertiliser application since it can be applied just before planting.

Zero- and reduced tillage data on the establishment of wheat after rice in the sub-continent is presently being compiled. Table 1 shows some of the data from Nepal. It shows that surface seeding and reduced tillage with the Chinese drill perform significantly better than the traditional system. Yields and thousand grain weights are higher, and costs of production are lower. Data from Pakistan in Table 2 also show that zero-tillage with an inverted-T coulter drill gave better yields than traditional planting, with greater benefits where planting was closer to the optimum date. More than a ton of extra yield was obtained, on average, with zero-tillage over farmer practice when planting was 24 days earlier. Data is also being compiled in India and Bangladesh on this innovative, cost reducing technology. What is needed is more support from research administrators to popularize these technology options in different wheat growing environments. Appropriate equipment needs to be made available to farmers with local artisans involved in the fine-tuning of this equipment to local needs.

Table 1: Data from a 1993/94-wheat establishment trial following rice on the Bhairahawa Agricultural Farm, Nepal (from Hobbs and Giri, 1996).

Method	Yield kg/ha	1000 grain weight	Cost to plow Rs/ha	Net Benefit Rs/ha	Extra days needed to plant[1]
Surface seeding	2775 a[2]	46.11 a	0	11485 a	0
Chinese seed drill	2831 a	45.43 b	600	12090 a	8
Farmers practice	2314 b	40.87 c	2300	8065 b	15

[1] Number of extra days needed for land preparation before seeding compared to the surface seeding.

[2] Figures followed by the same letter are not significantly different at 5% probability using DMRT.

Most of the irrigation given in South Asia is by flooding. This is a simple but not very efficient way to apply water. In NW Mexico, where water is a scarcer commodity, farmers have shifted over to a ridge and furrow system for planting wheat. The wheat and other crops are planted on the top of the ridge, with water passed down the furrow. This results in significant savings in water and increases the water use efficiency. This system is also being researched in the high production areas of India. New agronomy has to be developed for this system in terms of bed size, number of rows, fertiliser application, irrigation, weed control and variety selection. This is presently being done with good results. Early results show that variety selection is important with some varieties doing well on beds while others sacrifice yield. Similar results are found in Mexico.

The ridge and furrow system is also being researched one step further by following the wheat crop with another upland crop without tillage. This is called FIRBS (Furrow Irrigated Raised Bed Systems) in Mexico and ridge-till in other countries. It is particularly appropriate for cotton, maize and soybean systems where wheat follows these crops. Much more research is needed, especially the development of appropriate bed making and planting machinery. The four main advantages of this bed planting system are:

1. Improved water distribution and efficiency

2. Improved fertiliser efficiency. This system enables farmers to place the pre-plant applications below the bed and their top-dress nitrogen in the furrows and incorporate before irrigation.

3. It provides an alternative for weed control since cultivation can be done in the furrows. This is an important consideration since the grassy weed *Phalaris minor* has developed resistance to the herbicide Isoproturon, the most commonly used herbicide for control of this weed in India and Pakistan.

4. It helps reduce lodging because the wheat plants are not exposed to soft soil conditions after irrigation and more light can penetrate the canopy resulting in stronger plants.

Table 2: Comparison of zero-tillage and farmers practice for establishment of wheat after rice on locations in the Pakistan Punjab where the planting dates for the two methods differed, (from Aslam *et al.*, 1993).

Location	Wheat yield kg/ha		
	Zero-tillage	Farmer Practice	Days difference[1]
Daska site-2	3143	3209	10
Daska site-1	3842	2735	13
Ahmed Nagar	4308	3526	20
Maujianwala	2689	2198	22
Mundir Sharif	4245	2660	33
Daska site-3	3838	3420	44
Average	3677 a	2598 b	24

[1] Means followed by the same letter do not differ significantly at the 5% level using DMRT

The interaction of the TCE and INM research themes is very important. Initially, the development of the package of practices for these new establishment options must include a fertiliser strategy. Results from the region show that when nitrogen is broadcast on the surface at planting in zero-tillage (surface or inverted-T coulters), conditions up to 25% of the nitrogen is lost resulting in lower efficiency and yields. Results show that delaying the nitrogen application until later in the growth cycle can minimise this. Phosphorus and potash applications are also affected in systems where fertiliser cannot be placed by the seed drill. However, Indian data shows that these two elements can be surface applied without undue losses.

Zero and reduced tillage also has an effect on organic matter. The use of farm manures is complicated since they cannot be incorporated easily. By not disturbing the soil with tillage, organic matter cycling will be affected. Future research intends to look at some of these longer-term issues by initiating some medium-term experiments on tillage and monitoring various soil parameters over time. This includes measurements on soil physical, chemical and biological activity. Biotic factors would include soil borne and foliar diseases, insects (stemborers), rats and weeds. Interestingly, in the rice-wheat system, weeds are less with zero-tillage than conventional establishment methods. This is related to the different weed flora in the winter and summer seasons and the reduction in soil disturbance with zero-tillage. Research will also monitor some of the parameters outlined above on farmer fields where these new technologies have been. It may also be found that a rotation of tillage will be needed. Zero-tillage may be economic for a few years and then be followed by conventional tillage to break weed, pest and disease cycles. This would allow incorporation of organic manures which are normally not applied every year.

In the rice-wheat system, any of the benefits of reduced and zero-tillage is lost when puddling of the soil for rice is done. There are situations where rice can be grown without puddling, especially where soil texture is heavy and water tables are near the surface. In these situations introduction of direct seeded rice without puddling may be very beneficial for the system.

I conclude that these changes in tillage and crop establishment are some of the most exciting opportunities available to improve wheat system productivity in a sustainable way in the Indo-Gangetic flood Plains while raising input efficiency, lowering costs, saving fuel and reducing the intensity of machinery use. Integrated nutrient management issues are an important component of this research. Also important is the acceleration of the adoption of these options by farmers. Incorporating a strong farmer participatory approach in the research where the farmer is an active member of the research team from the beginning can best do this. Private sector (local artisans and machinery makers) and NGO involvement would also help extend this productivity enhancing technology to a wider clientele.

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Productive and regenerative agricultural systems for marginal and degraded soils of Latin America

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Introduction

First estimates of degraded land in Latin America indicate that over 50% of agricultural lands (92 million ha) and 14% of pasture lands (78 million ha) are undergoing some form of degradation (Oldeman *et al.* 1990). Degradation is often associated with monocropping or overgrazing. Even though the region is one of the few remaining areas of the world where agricultural expansion is possible and has been referred to as the "one of the last agricultural frontiers" (Borlaug and Dowswell 1994), the need for reversal and a prevention of land degradation has become an urgent priority for most of the tropical Latin American countries. In addition, important biodiversity reserves are under increasing threat from agricultural expansion into the forest margins and savannas (Smith *et al.*,1997; Thomas *et al.*, 1995).

Farmers in the region who have assets to realise are responding to the need to implement resource conserving technologies such as no-tillage systems (Scherr and Yadav 1996; Smith *et al.*, 1997) which now occupy some six million ha in Bazil alone (C. Magno da Rocha, *pers. comm.).* Other promising technologies such as integrated crop-livestock systems, green manuring, agroforestry, although proven to be successful on experimental research stations (Thomas *et al.*, 1995), are only being adopted slowly in the region.

Here I describe some technologies with potential to reverse soil degradation and provide an example of how participatory approaches can result in increased adoption of a resource conserving technology.

Technologies to maintain soil productivity and reverse soil degradation

Research at CIAT and collaborating NARS (National Agricultural Research Systems) of both Brazil (EMBRAPA - Brazilian Agricultural Research Enterprise) and Colombia (CORPOICA - Colombian Agricultural Research Corporation) has demonstrated the beneficial effects of introduced grass and grass/legume pastures on animal performance and soil fertility in pasture and crop-pasture systems. A summary of these results are shown in Table 1 and references therein.

Grass/legume pastures can double animal live weight gain per head and increase productivity 10-fold on an area basis compared with the native savanna grasses (Thomas and Lascano, 1995). Dates of first calving occurred 30% earlier in cows grazing grass/legume pastures compared with native savanna and calving intervals were also shortened by 22% (Thomas and Lascano, 1995). Lascano and Avila (1991) also demonstrated a 20% increase in milk production from cows grazing a grass/legume pastures versus grass only pastures. These results are demonstrable in both degraded and non-degraded forest margin and savanna eco-systems with a range of grasses and legumes (CIAT 1992).

Yields of an upland rice crop were more than doubled when the crop was sown on land previously under a 10 year old grass/legume pasture compared with a grass only pasture when both received P but no N fertiliser (Thomas *et al.*, 1995). Table 1 also shows benefits of the improved pastures on soil chemistry, physics and biological activity. Grasses are probably responsible for the physical effects rather than the legumes but in most cases the beneficial effects are increased in the presence of the legume. An additional benefit, although perhaps without immediate benefit for the farmer, is the finding that introduced grasses from Africa can sequester substantial amounts of carbon below 40 cm in Oxisols of Colombia (Fisher *et al.*, 1994). The extent of this finding is currently under investigation but similar results have been reported in Brazil and Peru (R. Boddey; R. Vera, unpublished).

Although improved grass/legume pastures bring many benefits, the rates of adoption are relatively low and guidelines for the maintenance of the legume component remain elusive. Rotation of pastures with crops in short 3-5 cycles offers a means to avoid the problem of lack of legume persistence and the residual effects of fertiliser, applied primarily to the crop, can result in a faster establishment and better quality of a subsequent pasture (Thomas 1995; Thomas *et al.*, 1995). In Latin America such integrated crop-livestock systems will probably require additional policy incentives for increased adoption (Smith *et al.*, 1997). For example, farmers could be paid for environmental services such as carbon sequestration mentioned above, which would stimulate wider use of improved grass/legume pastures.

Green manures are advocated for use as a source of nitrogen and ground cover in areas at risk from erosion, and are used in Southern Brazil and Central America. The use of *Mucuna pruriens* in Central America for example, has been hailed as a success story (Bunch, 1990). While there are undoubted benefits for soil conservation and subsequent yields of cereals such as maize, little is known about the efficiency of these systems. Work on green manures in Colombia has shown that rates of decomposition are very rapid resulting in large amounts of nitrate-N (>100 Kg N/ha) below the rooting zone of subsequent crops (Figure 1), suggesting an inefficient system with increasing risk of groundwater contamination. The fact that farmers still apply N fertiliser in the *Mucuna*-based system (Bunch, 1990) suggests that much of the N in the green manure could be lost via leaching. Further data on this and on approaches to improve this technology are needed in order to ensure that an apparent resource conserving technology is not, in fact, creating new environmental problems.

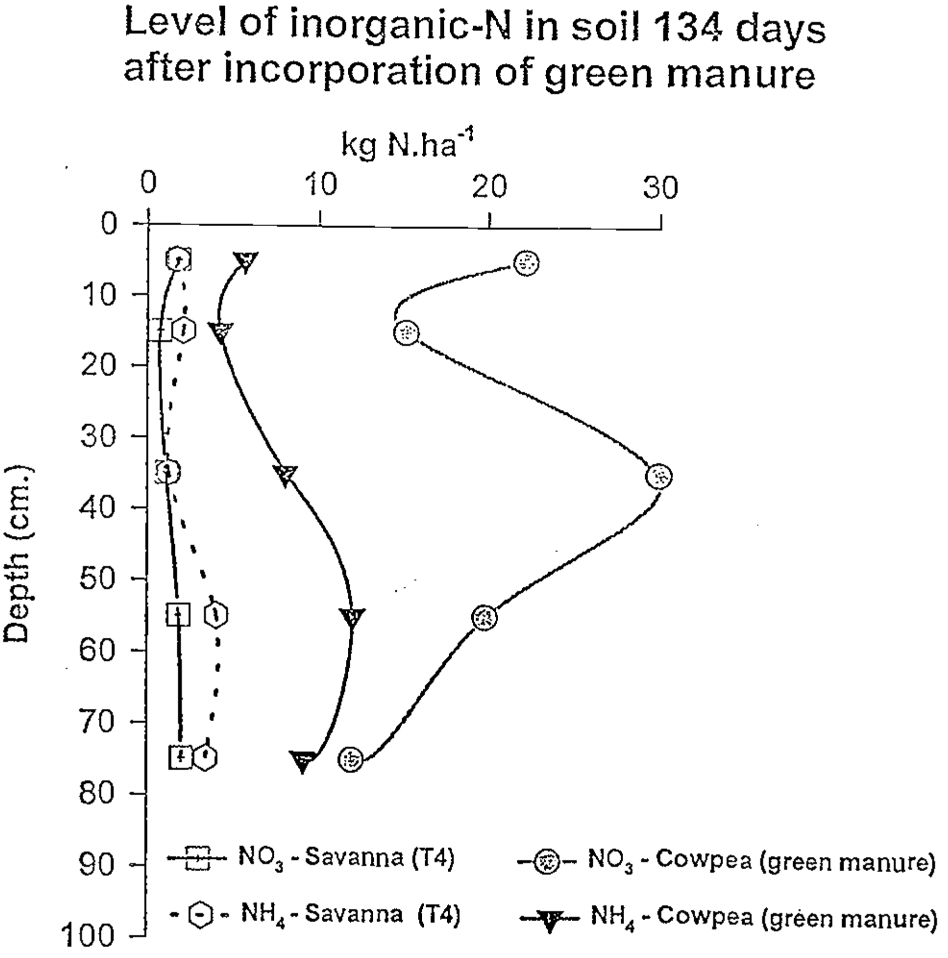

Figure 1.

Adoption of natural resource conserving technologies

The IBSRAM-sponsored report on soil, water and nutrient management (Greenland *et al.*, 1994) highlighted the lack of adoption of existing natural resource conserving technologies. Increasing emphasis is now being given to the "farmer-first" or "bottom-up" approach. The success of these approaches depends in part on the existing relationship between the farmers and researchers and/or extensionists. If this is strong and there is a two-way exchange of information and experiences then there may be no need to advocate a change in approach. An example from the Colombian Andes is presented here to illustrate how the "farmer-first" approach can be successful in improving the adoption of soil conservation barriers (Ashby *et al.*, 1996). The hillsides of the Cauca valley in the southern part of the central Cordillera near Cali, Colombia, form part of a marginal coffee growing region characterised by eroding slopes. Losses of up to 100 t soil/ha can occur within 10 months representing about 5% of the top soil. The local extension agency had been working for over 10 years in the area promoting erosion barriers such as "citronella" (*Cymbopogon nardus*) and "limoncillo" (*Cymbopogon citriatus*) but rates of adoption were poor up to 1991. Population densities in the pilot area chosen for the study were around 132 persons/km^2 similar to estimates for Bolivia, Ecuador and Peru. Farmers in the study area grow cassava, maize and beans to supplement income. In 1991 only 13 farmers were using live barriers and all but two were receiving credit and/or technical assistance. An on-farm trial was established to test six different plant materials for erosion control and farmers were invited to assess these materials and given them a preference ranking. At the same time extensionists were trained in participatory methods and were asked to suspend their usual recommendations for use of live barriers (*e.g.* adherence to use of an "A-frame" for contours). After thoroughly discussing the material in groups of both farmers and extensionists the farmers then had the option to select one or more planting materials to try out on their own farm in whatever way they wished. This activity was repeated for 3 years with different farmers. Farmers paid for the material at cost and could give other farmers planting material if requested.

In the selection study trial farmers preferred first, a cut-and-carry grass called "pasto telembi" (*Axonopus scoparius*) for incorporation into live barriers and second, sugar cane (*Saccharum officinarum*). Vetiver grass (*Vetiveria zizanioides*), technically proven to be the best in terms of erosion control was ranked last out of six by the farmers. They preferred a plant with short-term direct utility such as fodder for animals or for sale to other farmers or sugar cane for domestic consumption. Thus they were willing to forego maximum erosion control for an income-generating alternative.

Over three years 115 farmers participated in the study and recommended the barriers to another 146 farmers. Thus 261 farmers had planted live barriers, 56% of them as a result of recommendations of other farmers. From 1991 the number of farmers who had established live barriers independently of any credit incentive had risen from 2 to 261 by 1994. Further a process of spontaneous adoption (without direct intervention of extension agents), was stimulated by farmer-to-farmer contact which was of equal magnitude to that promoted by the extension program (field trips and participation in the on-farm trial assessment exercise).

The results show that technologies can be adopted rapidly if they are thoroughly evaluated by local farmers and adapted to local conditions. In addition, farmer-to-farmer transfer of information is as effective as traditional extension activity.

Conclusions

Technologies that improve or conserve the natural resource base are available for Latin America but there are few examples of successful introduction and adoption. Closer examination of both the policy and technology options are required for better targeting of options. The "farmer-first" approach has proven potential to increase rates of adoption of resource conserving technologies.

Table 1. Beneficial effects of grass/legume pastures in agropastoral systems

Parameter	Benefit	Reference
Animal Production		
Animal live weight gain	++	Thomas *et al.*,1995
Reduction of age at first calving	+	Thomas and Lascano., 1995
Reduction in calving interval	+	Thomas and Lascano., 1995
Milk yields	+	Lascano and Avila., 1991
Crop yield		
Rice after pasture	++	Thomas *et al.*, 1995
Soil improvement		
Total soil carbon	+	Fisher *et al.*, 1994
Soil carbon in sand fractions	++	Guggenberger *et al.*, 1995
Potential N mineralisation	+	Rao *et al.*, 1994
Wet aggregate stability	+	Gijsman and Thomas., 1995a
Water infiltration rate	+	Gijsman and Thomas., 1995b
Microbial-P	+	Oberson *et al.* 1997
Nutrient cycling via litter	+	Thomas and Asakawa., 1993 Guggenberger *et al.*, 1995
Earthworm populations	++	Decaens *et al.*, 1994

+ = an increase of <100% compared with grass-only or native savanna pastures.
++ = an increase of >100% compared with grass-only or native savanna pastures.

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Relevance of soil micronutrients in long-term fertility decline

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The relevance of soil micronutrient fertility has been well recognised since the advent of the green revolution when increased crop production increased the demand on soil for nutrients. The emergence of multi-micronutrient deficiencies has led to a considerable decline in the productivity and sustainability of several cropping systems (Takkar and Nayyar, 1979; Singh and Saha, 1995). Besides zinc, boron deficiency has been found to be a serious constraint in achieving high crop yields in calcareous soils as well as in red and lateritic soils of Bihar and west Bengal (Sakal *et al.*, 1997). India will need Mt of food grains, apart from 26 Mt of oilseeds, by the year 2000 AD to feed an ever increasing population which may further dimish the fertility of soils; hence it is relevant to know the micronutrient fertility of Indian soils and how it may be enhanced to ensure sustainable, crop production and better soil health and environment.

Micronutrient deficiencies in Indian soils

Indian soils have sufficient total micronutrient content but their plant available contents are low. Field scale zinc deficiency in rice was first noticed in 1965 in the foothills of Himalaya (Nene, 1965). Analysis of 248,000 surface soil samples have indicated an average 48, 11, 4, 2 and 33% deficiency of Zn, Fe, Mn, Cu and B respectively depending upon different soil-crop-management situations (Table 1) (Singh and Saha 1997). Most of the Indian soils are adequate in copper and molybdenum. Iron deficiency is most common in calcareous alkaline soils having low organic matter. Field scale manganese deficiency has been reported in wheat under rice-wheat systems when adopted for 7 to 10 years in coarse textured Ustochrepts of Punjab. The problem of boron deficiency occurs widely (22-68%) in red and lateritic soils of West Bengal, Orissa, and North-eastern regions, and in red soils and calcareous soils of Bihar (Sakel *et al.*, 1997).

Multi-micronutrient deficiencies

In high potential areas, intensive agriculture and the use of high amounts of NPK fertiliser have resulted in greater depletion of the soil available micronutrient reserve. Multi-micronutrient deficiency is emerging because of annual grain harvests at 10-12 t/ha. Repeated surveys have revealed that the status of available zinc has risen thereby reducing its deficiency by 15-60% in different soils over a period of 15-20 years due to regular use of zinc by farmers. However, deficiency of Fe has increased from an initial 4% to 22% while Mn has increased to 20% in some districts of Punjab where rice-wheat is grown. This causes a marked decline in wheat productivity if it is not corrected (Nayyar *et al.*,1990; Singh and Saha, 1995).

Long-term micronutrient fertility decline in highly productive soils

With the advent of the green revolution highly productive areas are producing 15-20 t/ha/yr biomass and so remove greater amounts of nutrients from the soil. Gradually, multiple deficiencies of Zn, Fe, B and of late Mn have emerged in many areas. Therefore, enhancement of soil micronutrient fertility is of paramount importance for achieving optimum crop yields.

Long Term Fertiliser Experiments on Ustrochrepts at Ludhiana indicated a significant decline in maize productivity after 10 cropping cycles of a maize-wheat-cowpea fodder sequence because DTPA-Zn dropped to 0.68 from an initial 1.1 mg/kg. The productivity of maize improved progressively with the addition of zinc from 9.2% in 1980 to 20.5% in 1986, although no significant effect was observed on wheat and cowpea yields.

Table 1. Extent of micronutrient deficiency in Indian soils

State	No of soil samples	Per cent deficient samples				
		Zn	Cu	Fe	Mn	B
Andhra Pradesh	8158	49	<1	3	1	-
Assam	12165	34	<1	2	20	-
Bihar	19214	54	3	6	2	39
Delhi	201	20	-	-	-	-
Gujarat	29765	24	4	8	4	2
Haryana	21848	60	2	20	3	-
Jammu & Kashmir	93	12	-	-	-	-
Karnataka	27860	72	5	35	17	32
Kerala	650	34	31	<1	-	-
Madhya Pradesh	31966	44	<1	7	1	22
Meghalalaya	95	57	2	0	23	-
Orissa	16040	54	-	0	-	-
Punjab	16320	48	<1	14	2	-
Tamil Nadu	27733	59	6	17	6	8
Uttar Pradesh	25846	46	<1	6	3	24
West Bengal	6547	36	0	0	3	68
Whole India	248786	48	3	12	5	33

Source: Singh and Saha (1997)

In zinc deficient Ustochrepts of Punjab, Nayyar, *et al.*,(1990) reported the effect of six crop rotations viz: wheat-rice, gram-pearl millet, potato-cluster bean, raya-mash, wheat-maize. Application of 11 kg Zn/ha resulted in an increase of 2.75 mg DTPA-Zn/kg which declined to the critical level of 0.6 mg/kg after four cycles in all rotations except raya-mash and wheat-groundnut. The decline was fastest in the rice-wheat system. The response of rice-wheat to added Zn varied from 1.45 to 5.13 t/ha in the four cropping cycles. In similar studies, 11 kg Zn/ha when applied to groundnut in a groundnut-wheat rotation maintained adequate DTPA-Zn even after the 10th crop. Because a decline in Zn fertility threaten the sustainability of production systems, repeat applications of 5.5 kg Zn/ha to every fourth rice crop has becme necessary on these soils.

The high productivity of rice could not be restored to such sandy soils of the Punjab in the initial 3-5 years even following soil puddling and balanced applications of NPKZn due to low Fe availability to plants (Nayyar *et al.*, 1990). Later the availability of Fe increased by 49-56% and its deficiency disappeared due to the favourable effect of submergence. Incorporation of green manure or FYM with three foliar sprays of 1% ferrous sulphate solution gave the highest grain response of 2670 kg/ha. Application of ferrous sulphate alone did not enhance Fe fertility in such sandy soils (Takkar and Nayyar, 1979).

With time the problem of Mn deficiency has gradually become more pronounced leading to very low productivity of wheat over 6-9 years of rice-wheat cropping once the Zn and Fe deficiencies were corrected. Wheat yields increased from 1.7 to 2.1 t/ha if three foliar sprays of 1% $MnSO_4$ were applied, one before first irrigation and two afterwards. Both soil and foliar sprays are effective but foliar sprays of Mn are more economical.

In highly productive areas such as Pantnagar (Hapludolls), producing 20-25 t/ha biomass/yr the productivity of rice-wheat-cowpea fodder sequence declined after 12 annual cropping cycles in a NPK treatment due to depletion of available Zn from 2.54 mg/kg to 0.97 mg/kg soil. Foliar sprays of 5 kg/ha zinc sulphate increased the Zn uptake by rice and restored the productivity of the system. The increase in grain productivity due to Zn addition was 1.1-0.8 t/ha of rice and 0.4-0.96 t/ha of wheat, over that obtained using optimal NPK alone (Nambiar 1994). Thus there is a need to index the depletion rate to forewarn against the occurrence of such deficiencies and monitor different micronutrient pools to allow for their effective amelioration.

With multiple cropping the Zn status of sandy loam soils of Anand declined by 43% in 10 years below the critical level of 0.5 mg DTPA-Zn/kg and a supplemental dose of 5 kg Zn/ha was required to sustain the productivity of the systems (Dangarwala *et al.,* 1994). Available Fe was depleted by 12% over the first 4 years and by 36% after 10 years. Manganese and copper remained adequate even after 15 years of multiple cropping. Available B increased over 10 years as irrigation water contained appreciable quantities of boron. Use of organic manure at 5t/ha enhanced soil fertility and crop productivity in these sandy loam soils. The net depletion of DTPA Fe, Mn, Zn and Cu was higher in NPK compared with a higer (150% NPK) fertility level. Thus, imbalanced fertilisation without use of organic manure resulted in the emergence of multiple soil micronutrient deficiencies.

Long-term micronutrient fertility decline in low productivity soils

In low crop productivity areas with either low production potential or unexploited high potential, the depletion of soil micronutrients is not as great as in highly productive areas with similar soils. Therefore such areas can sustain yields for longer. For example, young alluvial soils of Barrackpore the yields of rice, wheat and jute (fibre) in sequence did not decline significantly even after 20 years cropping even though available zinc was low.

On Swell-shrink soils, 40-55% are zinc deficient. Improvement of zinc fertility is essential to enhance yields and use efficiency of NPK fertilisers. The productivity of wheat-rice and soybean-wheat can be increased significantly with applications of 5.5-11 kg Zn/ha after a period of 4 to 6 crops (Rathore *et al.,* 1995). However, on the Ustochrepts of Coimbatore, there was no significant decline in grain productivity of finger millet, maize and cow pea fodder even with multiple cropping though available Zn declined from 2.60 to 0.34 mg/kg soil in the NPK treatment (Nambiar, 1994). This suggests the need to study the contribution of various micronutrient pools and their dynamics to know better the release pattern of inherent soil micronutrients.

Soil micronutrient fertility decline in problem soils

Alkali soils are generally deficient in zinc. Maintenance of zinc fertility has much relevance because productivity and sustainability of crops in such soils cannot be maintained by removing calcium deficiency/Na toxicity unless zinc stress is removed simultaneously (Nayyar *et al.,* 1990; Singh *et al.,* 1987). Zinc efficiency was greatest when both zinc and gypsum were added compared to either zinc or gypsum alone. The build up of zinc fertility helped in the balanced nutrition of rice. The efficiency of applied zinc is very low and farmers have to apply large quantities so it is important to develop IPNS technology for enhancing zinc use efficiency and its residual effect to subsequent crops (Singh and Abrol 1985 and 1986).

Young alluvial calcareous soils of Bihar containing 20-45% $CaCO_3$ are highly deficient in Zn and B. Long-term field studies at Pusa revealed that the productivity of rice and wheat declined with cropping on because of Zn deficiency. Application of 10 kg Zn/ha to the first rice crop followed by 5 kg Zn/ha to every fourth crop thereafter was found to be the best mode of zinc application for maintaining optimum productivity of the rice-wheat system.

Sakal *et al.,* (1997) reported that the decline in micronutrient fertility under cereal-cereal rotation was higher than rotations having oilseeds and pulses which removed small amounts of micronutrients from the soils. Besides zinc, application of 1.0-1.5 kg B/ha significantly improved the productivity of oilseeds, pulses and other crops in these calcareous soils.

Long-term effects of integrated use of organic manures and fertilisers on soil micronutrient fertility

The integrated effects of 10-15 t/ha organic manure and NPK fertilisers was greater in all long-term fertiliser experiments for sustaining high yields over NPK and NPK+Zn. Available Zn in soil increased considerably with NPKZn, and more so with the incorporation of 10-15 t/ha FYM + NPK over 15-16 years. Availability of Fe, Cu and Mn increased in NPK + FYM and remained quite high in spite of continuous intensive cropping and did not indicate any adverse effects on crop production (Nambiar, 1994).

Prasad and Sinha (1996) reported that incorporation of wheat and rice roots and stubbles to soil recycled 28, 28, 41 and 40% of the total removal of Zn, Cu, Fe and Mn by wheat and 31, 21, 11 and 79% by rice on Calciorthents in Bihar. Addition of crop residues of wheat and rice to soil met on, an average, 51, 69, 79 and 68% of the Zn, Cu, Fe and Mn needs of wheat and 61, 82, 73 and 83% of the needs of rice in calcareous soils. Green manuring proved superior in improving rice yield by mobilising native soil Fe compared to applications of ferrous sulphate alone on Ustochrepts of Punjab (Nayyar *et al.*,1990).

Monitoring of micronutrient status periodically would help in identifying incipient micronutrients deficiencies in soils and allow adoption of suitable corrective measures to ensure high crop productivity.

Issues of soil micronutrient fertility and future research priorities

- Micronutrient deficiencies are widespread in Indian soils and multiple nutrient deficiencies are emerging in intensively cultivated, high production areas. There is a need for micronutrient indexing to forewarn of emerging problems in different soil, crop, and agro ecological situations.
- The fertiliser use efficiency of micronutrients for crops is low (0.5-2%). There is a need to develop IPNS technology using minimal amounts of organic manures for correcting micronutrient disorders, in a move towards sustainable farming at high levels of crop production with minimal use of agricultural chemicals.
- The quality and quantity of crop residues, organic manures and city compost with respect to micronutrients needs to be evaluated to promote their integrated use and to avoid yield decline.
- Continuous cropping depletes the soil micronutrients and causes a considerable decline in their uptake by crops. Technologies to produce micronutrient enriched seeds for better human and animals health are very much needed.
- There is a need to enhance uptake of Fe, Mn (elements which are inherently high in soil) or to select crops or crop cultivars with high absorption and utilisation capabilities.
- There is need for rigorous monitoring of the changes in soil micronutrients in different ICAR long-term fertiliser experiments so as to understand the causes of micronutrient fertility decline/build up and to develop models to recommend economical and efficient corrective measures for restoring sustainable crop production.

Conclusions

This paper summarises the long-term decline/build up of micronutrient fertility of Indian soils and their effect on the productivity of various cropping systems. In highly productive areas, a marked decline in crop productivity was recorded after 10-12 cropping cycles of maize-wheat-cowpea fodder sequence on Ustochrepts in Ludhiana and for a rice-wheat-maize fodder sequence on Hapludolls Pantnagar. On zinc deficient soils, regular application of 5-10 kg Zn/ha enhanced the fertility and productivity of soils initially but productivity declined due to the emergence of incipient deficiencies of Zn and/or B, Fe, Mn. The total removal of micronutrients by the crops declined with time. Nutrient indexing for precise and periodic forewarning of the emergence of multinutrient deficiencies in different agro-ecoregions, increasing fertiliser use efficiency through integrated and balanced use of organic and inorganic fertilisers for sustainable higher productivity, and producing micronutrient enriched seeds are priorities for the future.

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The role of livestock in integrated nutrient management in semi-arid west Africa

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Introduction

The soils of semi-arid west Africa are characterised by poor fertility. They are predominantly sandy, with total sand content ranging from 71 to 96% and have low organic matter and cation exchange capacity (Bationo and Mokwunye, 1991). Due to their texture and low organic matter content, they have poor structure, low water holding capacity and are prone to surface crusting and soil erosion (Valentin and Bresson, 1992). They are also deficient in nitrogen and, particularly, phosphorus (Penning de Vries and Djiteye, 1982). Low rural incomes, high cost of fertiliser, inappropriate public policies and infrastructural constraints prevent the widespread use inorganic fertiliser. At the same time, high population growth has led to a rapid expansion in cultivated land and caused a breakdown in the traditional fallow system used for maintaining soil fertility. Under this situation, as population pressure increases and fallow periods are shortened, animal manure becomes one of the principal sources of nutrients for soil fertility maintenance and crop production (Williams *et al.*, 1995).

The objective of this paper is to outline the role of livestock in integrated nutrient management in semi-arid west Africa. Farmers' strategies in the use of animal manure as well as research efforts to better understand the process of nutrient cycling through livestock in mixed farming systems are described. The paper concludes by suggesting ways in which research, government policies and farmers' practices could be coordinated to ensure sustainable nutrient management and agricultural development.

Livestock production and soil fertility management

A continuum of livestock production systems, ranging from pure pastoralism to integrated, mixed, livestock-crop production enterprises, are found in semi-arid west Africa. To adapt to the large seasonal variation in the availability and quality of forages, pastoralists have developed strategies of seasonal movements of herds. They exchange animal manure for crop residues and water owned by farmers. However, the pastoral system of production is in a state of transition and is becoming less sustainable due to increasing population pressure and severe droughts. In the light of these developments, integrated crop-livestock systems offer a viable solution to the crises of pastoralism and extensive cropping based on shifting cultivation.

Under mixed farming, the most important interactions between crop and livestock production involve the use of animal traction and manure for cropping and the feeding of crop residues and other forages to animals. While forage and manure linkages are common to nearly all mixed farming systems, animal traction is mainly associated with cash cropping (McIntire *et al.*, 1992). The cycling of biomass through animals constitutes an essential linkage between livestock, soil and crop productivity in mixed farming systems.

Nutrient cycling by ruminant livestock

The types and amounts of animal-excreted nutrients available for recycling depend upon the types and numbers of animals kept by farmers, animal diet and the spatial and temporal distribution of livestock. Forage intake is greatly affected by seasonal forage availability (Guérin *et al.*, 1988; Schlecht, 1995) and the quantity and composition of manure is a function of feed intake and quality (Powell *et al.*, 1994; Schlecht *et al.*, 1997). Other studies have addressed the fate of the nutrients excreted and the efficiency of their use by crops (Brouwer and Powell, 1995; Somda *et al.*, 1995).

Several quantitative assessments have been carried out on the contribution of livestock to the nutrient flows in farming systems of semi-arid west Africa (Quilfen and Milleville, 1983; Landais and Lhoste, 1993; Fernández-Rivera *et al.*, 1995). Despite the extremely low vegetal mass left on the rangelands and the crop fields by the end of the dry season, total intake by livestock measured in village sites in Niger only amounted to 19% of the annual production of forages and 10% of the weeds and crop residues left on the fields after harvest (Hiernaux *et al.*, 1997). If not destroyed during bushfires, a large fraction of the vegetation mass produced during the wet season is either consumed by insects or returned to soil as litter, whose decomposition is accelerated by trampling (Hiernaux and Fernández-Rivera, 1996). These data indicate that the contribution of livestock to direct recycling of organic matter and nutrients is relatively modest. The main role of livestock involves the transfer of organic material and nutrients from the grazed lands to selected crop fields. This concentration of nutrients on targeted areas offers the farmer an opportunity to either reduce the heterogeneity of soil fertility in his fields, following a risk aversion strategy, or increase productivity, following an intensification strategy (Buerkert, 1995). Livestock also affect nutrient cycling indirectly through the effects of grazing on vegetation, the impact of trampling on soil structure, surface crusting and water runoff, and through soil tillage whenever animal traction is used.

Farmers' practices and opportunities for improvement

Manure acquisition for soil fertility restoration occurs in three main ways: corralling of household animals on crop fields, collection and hand-spreading of manure retrieved from barns and stalls, and the use of pastoralist herds on a contract basis. Manure is rarely applied over an entire field, but rather in specific spots deemed to be nutrient deficient. This process, when carried out over a number of years, eventually results in the manuring of the entire field. Experiment station trials have shown that corralling, because it returns both manure and urine to the soil, results in greater crop yields than when only manure is applied (Powell and Ikpe, 1992). Corralling also requires no labour for manure handling, storage and spreading. Approximately 40 to 60 % of the N excreted by ruminants is in the form of urine and most of this nitrogen is lost by volatilisation when urine is deposited on the soil (Somda *et al.*, 1995). Thus the use of litter beds in corralling sites could reduce the nitrogen losses and accelerate the mineralisation of the coarse material used for bedding (Camara, 1996). For farmers who rely on collection of manure, appropriate methods (*e.g.* bedding, composting) need to be designed to minimize nutrient losses and low-cost implements developed to facilitate the spreading of compost over the typically large area cultivated in west Africa. The rates and timing of manure application could be better adjusted to the needs of specific crops reducing losses through leaching (Brouwer and Powell, 1995). Improved use efficacy of available nutrients can also result from better use of low quality feed such as crop residues (Fernández-Rivera *et al.*, 1994) or supplementation with high quality forages such as cowpea hay

(Kaasschieter and Coulibaly, 1995). Legume crops can increase the availability of protein for human and livestock as well as provide nitrogen to the soils (Mohamed-Saleem and Otsyina, 1986). However, there are limits to the transfer of nutrients by livestock. To replenish the nutrients removed from cropland with animal manure large numbers of animals and areas of rangeland, relative to the area cropped, are required (Fernández-Rivera *et al.*, 1995; Turner, 1995). Such opportunities are likely not to exist as cropped areas expand. Similarly, the capacity of legumes to provide nitrogen is limited by their high requirements for phosphorus and other minerals (Breman *et al.*, 1996).

Introduction of external sources of nutrients

External nutrient inputs are needed to render west African agriculture more sustainable and productive (Breman *et al.*, 1990; de Leeuw *et al.*, 1995; Williams *et al.*, 1995; Duivenbooden, 1996). There are two possible ways to introduce nutrients from external sources into mixed crop-livestock production systems. A well known path consists of applying chemical fertilisers to cropland. The optimal use of inorganic fertilizers requires simultaneous applications of organic amendments to avoid severe soil acidification (Pichot *et al.*, 1981; Bationo and Mokwunye, 1991; Juo *et al.*, 1995). The second path consists in increasing animal feed and its nutrient content in order, first, to improve animal nutrition and performance, and second, to retrieve more organic matter and nutrients in animal excretions for use by crops. There is need to determine which combination of these two methods will be the more successful under particular farming systems and farmer resource endowments.

Future prospects for improved animal and manure management systems

Farmers keep different species of livestock and practice different management and production strategies according to their resource base and the varying levels of assets they command. The initial challenge to research and technology development is to identify, in a participatory manner, the constraints and opportunities for improving nutrient management. The strategies to use will be dictated by the stage of evolution of crop-livestock production systems. For example, in systems where manure use is already significant, the problem will be how to improve the efficiency of nutrient cycling, while in systems where crop and livestock production are still independent and manure is obtained through contracts between farmers and pastoralists, the strategy might be to develop ways to ensure that contracts are as efficient as possible. In all instances, farmers' views and practices need to form the cornerstone of new and improved methods. Local resource-use institutions will need to be strengthened or, where these institutions have proved inadequate, new ones established to ensure that herd mobility, which constitutes the basis of nutrient transfer from range- to crop-land, is not jeopardized. Government policies are also needed for encouraging the adequate and timely supply of purchased inputs.

Research is required to assess the impact of livestock in the agro-ecosystems and in the nutrient dynamics within the farming systems. There is a specific need for models that account for the complexity of soil-plant-livestock interactions at various spatial levels. These needs can only be satisfied through international and interdisciplinary cooperation.

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Integrated nutrient management in multispecies farming systems at the forest/agriculture interface

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Small-holder farming systems: the breaking point in development

The general pattern of agricultural development has involved the transition from sustainable, low input/low output farming systems where crop production is supported by biological processes, to mechanised crop productions systems maintained by agrochemicals (Figure 1). At low population densities traditional agricultural communities have been able to exploit extensive natural resources to provide most of their maintenance requirements with additional arable crops grown using the natural fertility developed under fallows or on small plots enhanced with dung inputs from domestic stock.

With burgeoning populations and decreasing land area *per capita* there is an increasing requirement for small-holders in many regions of the tropics to achieve crop yields equivalent to those on commercial farms with lower resource inputs (Bunting 1991). The natural carrying capacity of the forested zone for humans is governed by soil nutrients (Barnes and Lahm 1997); above this level, external resources are required to maintain food production. For many, supplies of appropriate inorganic fertilisers (and improved crop varieties) are often precluded by high cost, poor distribution, lack of rural credit systems, or a combination of these factors. As a consequence many small-holder farmers are struggling to support a basic livelihood on resources available within their farm catchment and are increasingly dependent on non-farm income to purchase food and other necessities.

At the other extreme, declines in cereal yields of large scale, commercial farming systems have been recorded over the last decade in many regions of the tropics where near optimum requirements of agrochemicals are presently available (Syers, 1997). This trend appears to be related to decreasing soil organic matter content in many of these soils under continuous cultivation. The incorporation of more crop residues on the fields, and alternative management practices such as direct drilling and minimum tillage, can improve the sustainability of these cropping systems (Greenland, 1994, Fernandez, *et al.,* 1997). However, the amounts of organic matter required to restore the production potential of degraded farm land are often far beyond those available to many small-holder farmers, while the size of the farm often precludes the option of extended fallows. Such development of the natural capital brings benefits to farmers only after four to six years and absolute poverty levels in many tropical countries makes it very difficult for them to make such an investment (Izac 1997). Hence many small-holder farmers are caught at the interface between traditional farming systems and modern farming systems in having insufficient natural or fiscal resources to capitalise on the productive potential of their farms. Improving their food sufficiency and farm income may require a more explicit recognition of the sustainable yield potential of these farms within the constraints of available organic resources, mineral fertilisers and labour under which they operate.

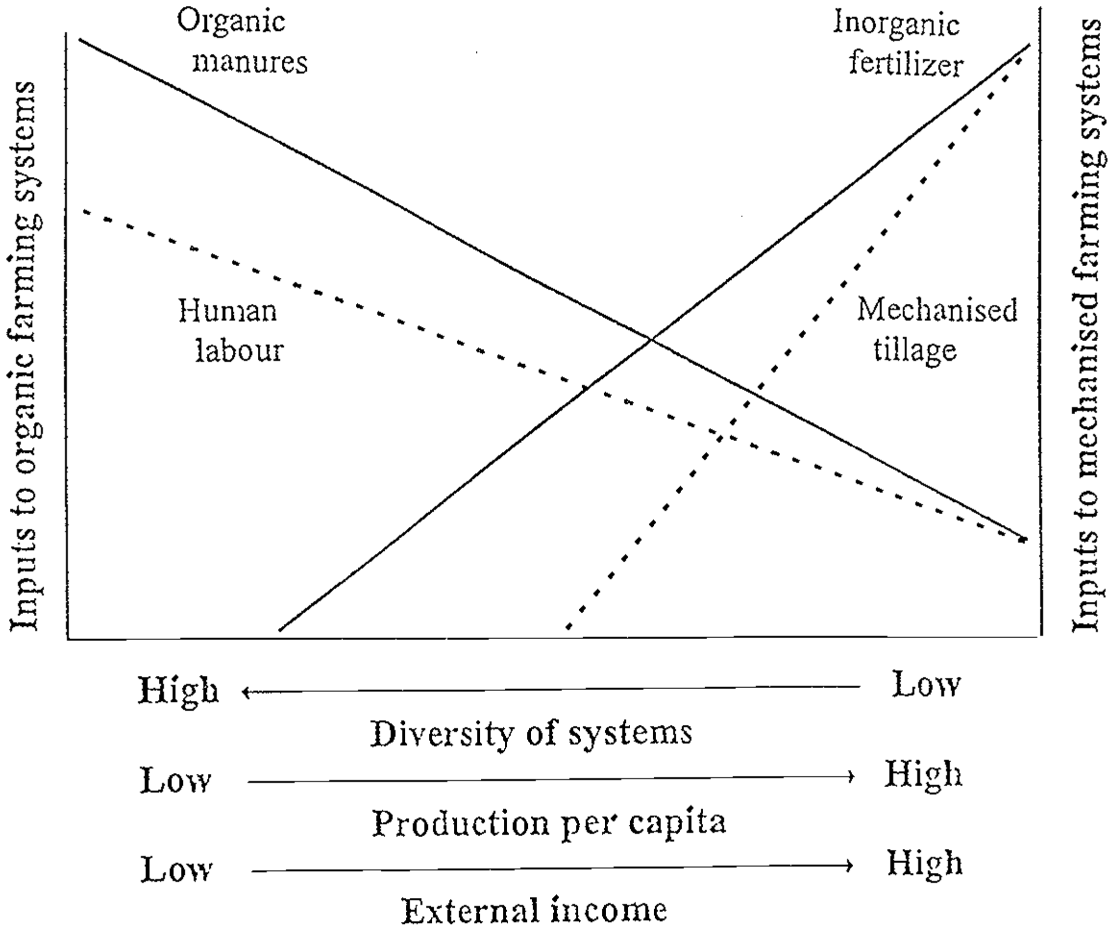
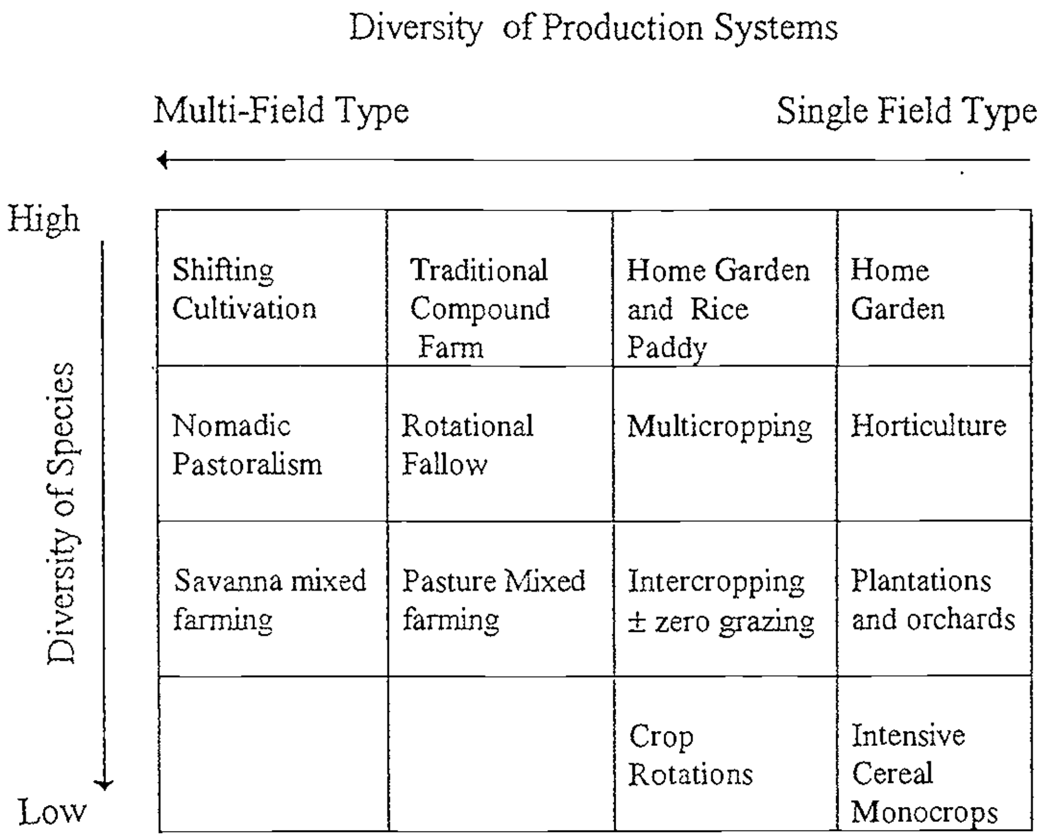


Figure 1. Changes in resource utilisation and farming system characteristics associated with agricultural development. The sustainability of small holder farming systems at the interface of traditional and modernist practices depends on the balance of internal organic resources and external inputs.

Techniques for integrated nutrient management (INM) in smallholder systems are not, therefore, simply a question of modifying agronomic practices developed in high external input systems, but rather of developing approaches with farmers which have their roots in the culture, traditional management practices and uses of diverse natural resources. INM therefore needs to be considered within the wider context of farming systems to address three main areas of development:

1. A greater appreciation of the economic value of sustainably exploiting biodiversity in natural and multi-species farming systems for the provision of services and commodities which must otherwise be purchased.
2. Understanding of the functional roles of the natural biota which maintain many key functions of the systems and of how biota can be managed.
3. Improving the use-efficiency of organic matter and mineral fertilisers within the resource constraints of smallholder farmers.



Shifting Cultivation	Traditional Compound Farm	Home Garden and Rice Paddy	Home Garden
Nomadic Pastoralism	Rotational Fallow	Multicropping	Horticulture
Savanna mixed farming	Pasture Mixed farming	Intercropping ± zero grazing	Plantations and orchards
		Crop Rotations	Intensive Cereal Monocrops

Figure 2. Relationships between the diversity of productive units utilised by farmers, biodiversity of the managed species and intensification of crop production (after Swift and Anderson, 1993)

Farming systems in forested landscapes and the utility values of diversity

Tree savannas, seasonal forests and evergreen forests are the natural vegetation over much of the tropics and sub-tropics of S/SE Asia, Central and Southern Africa and South America. These regions contain a great range of different types of farming systems which can be broadly categorised on the basis of the diversity of different production units they utilise and the diversity of species they contain (Figure 2).

Farmers use both the biophysical patterns of diversity in the landscape (niches with different crop/soil/environment relationships) and the biological diversity to avoid risk to their livelihoods from perturbations in climate, pests and market economies (Carter and Murwira, 1995). The amount of plant biomass also has a critical role in conferring stability and resilience to the system by buffering the effects of climatic and ecological perturbations on agroecosystems, and providing a reserve pool of resources which can be drawn on in emergencies. The non-harvested biomass (Table 1) not only determines structural and functional properties of the system (modifying microclimate, soil protection and stability of water supplies) but also the habitat and resources for the biota mediating many key processes. With increasing intensity of land use, the amount of non-harvested biomass (particularly of trees) usually declines, both at farm and landscape scales, and many of these diverse maintenance functions are lost.

In considering the biodiversity of farming systems, it is useful to distinguish between the planned or managed diversity (plants and livestock selected by the farmer) and the associated biodiversity (Swift, *et al.*, 1996). The associated biodiversity includes non-economically productive plants (weeds, cover species, etc.), animals (including pests, agents of natural biological control) and microbes (pathogens, symbionts and soil microorganisms) which carry out many of the service functions outlined in Table 2. Decrease in species richness is commonly accompanied by intensification of management and the substitution of system regulation by largely biological processes (biological control, nutrient cycling) with a control of ecosystem function by industrial products (pesticides, mineral fertilisers). Traditional agropastoral and shifting agriculture depends on extensive natural systems for the provision of utilities (fuel, animal forage and non-timber products) and environmental services (reliable water supplies, maintenance of soil fertility). In shifting agriculture, which is typical of the higher rainfall zones, cultivated plots are of short duration and may contain up to six crop species (Ruthenberg, 1980). Close proximity to the forest, however, enables a wide range of animal and plant products to be harvested. In Southeast Asia, approximately 4,500 plant species of economic value have been recorded (other than timber trees) including 1135 medicinal plants, 389 edible fruits and nuts, 387 fibers and rattans, 147 poisonous and insecticidal plants and 110 spices and condiments (Soepadma, 1995). In contrast, livestock production is typical of the drier forest savanna zones where cultivated plots, fertilised by dung from the extensive natural grassland, can be of much longer duration and contain up to 40 species of annuals, perennial shrubs and trees (Ruthenberg, 1980).

Table 1. Functions maintained by non-harvested components of plant biomass in farming systems.

Component of non-harvested biomass	**Agroecosystem function**
Trees	Aesthetics. Shade Wind breaks. Habitat for associated biota (pests/pest control) Litter (soil protection) Affect hydrology Maintenance of soil fertility (tree fallows) Nutrient recovery to topsoil Nutrient capture from atmosphere
Weeds and cover species	Capture of plant nutrient excess Protection of soil surface against splash erosion; Improved infiltration. Habitat for associated biota (pests/pest control) Resources localising soil organism activities Nitrogen fixation by legumes. Microclimate and boundary layer Entrainment of wind and water-borne sediment
Crop residues	Mulch effects on soil temperature and moisture Protection of soil surface against splash erosion and capping (increased infiltration) Habitat and resources for associated biota Nutrient carry-over petween crops. Aggregate stabilization by microrganisms Maintenance of soil organic matter Complex Al, Fe and P
Roots	Binding soil structure. Creation of macropores and water conduits. Major contribution to soil organic matter. Nutrient carry-over between crops. Resources for beneficial and plant pathogenic soil organisms.

Table 2. Functional roles of associated biota in soils

Organism group	Function	Effects at plot scale
Fungi and bacteria	Aggregate stability	Reduced erodability of soils
	Capping	Surface runoff
	Decomposition and nutrient mobilisation	Trace gasses and nutrient dynamics, SOM precursors and turnover
Nematodes	Root feeders	Yield losses
	Insect parasites	Biological control
	Fungal feeders	Affect P uptake by mycorrhizas
Earthworms	Surface aggregates	Particle detachment, sheet erosion, soil compaction.
	Macropores, soil structure	Infiltration, bypass flow, root development
	Organic matter turnover	Nutrient release, organo-mineral complexes, OM distribution, enhanced yields
Termites - litter feeders	Crop damage	Lodging and yield losses
	Surface sheeting and soil structuring	As for earthworms but on large scale including piping of throughflow, reverse leaching of base cations
	Nest/mound formation	Nutrient concentrations, crop niches, enhanced yields
Termites - soil feeders	SOM turnover	Increase in available P

With increasing population densities, traditional farming systems become more sedentary and often comprise a mixture of different land-use systems under the control of the same household. These sub-systems may range from home gardens through rotational fallows to specialized field monocrops. The home gardens developed around the homestead in many areas of the humid tropics mimic many attributes of the diverse resources used in natural forests. The plots are usually small (c.0.5-2ha) but the planned diversity can comprise 100-200 species of trees, shrubs, vines, herbs and garden crops (Soemarwoto and Soemarwoto 1982; Ramakrishnan, 1992). The gardens are fertilised with household waste, pig and poultry manure so that the total productivity is extremely high and rarely nutrient limited. In India and Southeast Asia, rice paddies are often located at variable distances from the homestead. Long-duration cultivars are often grown close to the village to capitalise on the high fertility status of paddies maintained by ducks and pisciculture.

Farther away from the village, more nutrient efficient, short-duration rice cultivars are grown (Swift, *et al.,* 1996). Similar utilisation of different rice cultivars occurs in West Africa (Richards, 1985).

An analogous series of farming systems reflecting a reduction in the ratio of natural forests/fallows: cultivated land in arable systems is reflected in livestock management in the trend from extensive: intensive agropastoral systems, through mixed farming to stall-fed animals. An advantage of zero-grazing to the smallholder farm is that higher quality resources fed through a few securely-held animals increases not only the quality of animal products (growth rates, milk production) but also the efficiency with which high quality dung (and urine) can be recovered.

Most of these traditional and current smallholder practices are mechanisms for converting bulky plant materials with low nutrient concentrations, or soils of low inherent fertility, into nutrient rich patches where staple food crops or cash crops can be grown more productively (Table 3). As a consequence concentrations of plant-available nutrients on the plots are higher up the response curve for the crops than mean concentrations per unit area in natural biomass and soils. For example in Zambian chitemene systems (Araki, 1993) slash from the outfields is collected together and burnt in the infield systems. The amount of ash produced varied from about 1.2 t ha^{-1} near to villages where fallow biomass is smaller to 3.1 t ha^{-1} in plots 10 km from the village. Yields of finger millet showed a low, though significant correlation, with ash concentration because much of the fine ash (which has high concentrations of P) was lost from the infield by wind or rain wash. This also illustrates an apparent trade off between the cost/benefits of larger yields for more effort at a remote site compared with lower yields closer to the village. The cultivation of low value crops, such as cassava, on poor soils distant from the homestead reflects a similar process of risk assessment for resource investment by the farmer.

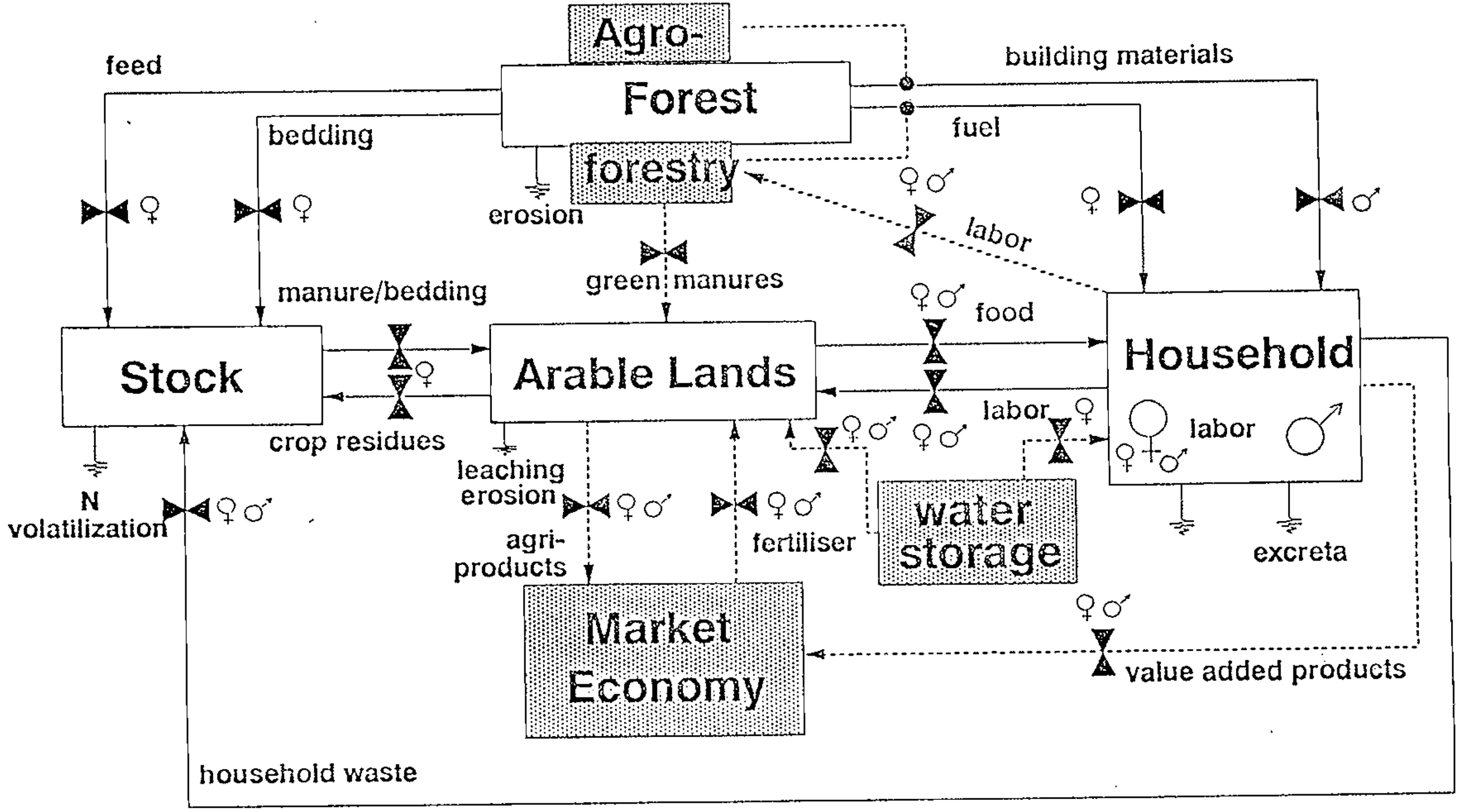
Table 3. Practices employed by traditional farmers to increase effective nutrient concentrations for crop growth

Practice	**Mechanism**
Natural fallows	Accumulation of nutrient capital with time
Fundakila system	Concentration of organic resources and topsoil in mounds, improved drainage
Chitemene	Slash from outfields burnt in infields where crops are cultivated
Agropastoral	Dung from extensive grazing collected from kraals
Sediment capture	Erosion management of shallow soils to create deeper sediment patches
Mixed farming	Convert mixed plant residues to quality dung by zero-grazed animals
Resource poor systems	Pit planting techniques
Composting	Increase mass of small volume resources

Often the most critical parameter in risk assessment by resource-poor farmers is the investment of labour by members of the family; particularly the women who carry most of the basic farming activities supporting the household. The gender-related resource transfers in a hill-farming system in India is illustrated in Figure 3. The main nutrient inputs to the system were through evergreen oak and grass harvested by woman on the surrounding hillslopes and fed to penned cattle together with crop residues and household wastes. Women also collected forest floor litter for animal bedding and firewood for the household. Carriage and spreading of the bedding/manure, planting, weeding and harvesting was also carried out by the women in addition to the usual functions of childbearing, educating the children and other household maintenance activities. The men, when not generating income elsewhere, were responsible for heavy manual activities such as collecting building materials, maintaining terraces and ploughing with the draught animals. The sustainability of this system was disrupted by a government policy of reforesting the hillslopes with pines and prohibiting the collection of tree products except fallen timber for fuel and pine needles for animal bedding. As a consequence of uncoupling the forest/agriculture interface nutrient deficiencies and poor yields were evident in crops on the terraces where the inadequate supplies of nutrient deficient dung/bedding were spread (personal observation). Both nitrogen fixing legumes and appropriate supplies of P would appear logical options to restore crop production in these farming systems. However, as in many smallholder farming systems it is likely that that adoption of any new technologies or practices would have to be preceded by establishing what could be done to reduce the demands on womens' time and energy. This might be achieved by increasing the accessibility of fuel (provision of woodlots), animal feed (grass bunds or tree legumes on field margins) or income generation (enhancing milk yields by worming cattle and improving feed quality).

While their traditional origins may be diverse, the pressures of increasing population densities have resulted in the functional convergence of many farming systems of the forest zone. These small-holder systems are characterized by a moderate to high diversity of crop species and varieties, a wide range of organic resources (though often limited amounts) which can be used to support crop production and small areas of land which can be placed under unproductive fallows. The inputs of fossil energy and agrochemicals are usually limited and, as a consequence, the functional roles of biodiversity in the system are often important in maintaining crop production and system functions than in highly mechanised farming systems.

Figure 3. Gender managed resource flows in a farming system in the hill region of North East India (Saxena, *et al.*, 1993)



Functional attributes of biodiversity in small-holder farming systems

The functional importance of crop and cultivar diversity in multi-species farming systems has been extensively reviewed elsewhere (Woomer and Swift, 1994, Swift *et al.*, 1996). Economic benefits to the farmer of planned diversity include:

- the utilisation of different production niches with the farm
- the provision of food, fuel and browse by multipurpose tree species
- the utility value of different crops (cropping time, storage, cooking properties, etc),
- the management of risk against natural catastrophes.

Many studies have also been carried out on the advantages of intercropping (two or more crops grown in the same field at the same time) which often, though not invariably, show higher yield than the single crops planted alone. Willey *et al.* (1986) suggest that these yield advantages occur where there is some synergistic interaction between the species which enables improved use of environmental resources. These mechanisms include microclimate (e.g. nurse crops) and the efficient capturing of light, water and nutrient above and below ground (which will be considered further below). Similar principles operate for tree/crop interactions in agroforestry systems (Ong 1991; Ong and Huxley, 1996).

Vandermeer (1990) observed, however, that the unpredictability of yield advantages in crop mixtures is often because the facilitative effects of the associated biota on plant production are unquantified. These functions include pollination, biological control of pests and diseases and enhanced plant nutrition by microbial symbionts (mycorrhizas, rhizobia and endophytes). For example, it has long been appreciated that the benefits of intercropping with legumes depend on the inoculation potential and activity of *Rhizobium* populations. However, the N balance of sugarcane crops in some areas of Brazil was inexplicable until the discovery of an intercellular, N-fixing endophytic bacterium which occurs throughout the plants (Dobereiner, 1993; Dong *et al.*, 1994).

The roles of specific components of the soil biota facilitating crop production are less readily defined than for pest species and their control agents because they act indirectly on the plant through the general maintenance of soil fertility. The processes of decomposition, soil organic matter formation and turnover, nutrient transformations and maintenance of soil structure are carried out by a highly diverse microbial community which exhibits great functional resilience (Giller, *et al.*, 1997). The maintenance of soil properties by biological processes appears, therefore, to be more critically determined by the properties, amounts and quality of the organic matter inputs to soils that by the diversity of the biota (Anderson, 1994). Notable exceptions are where the organisms act as transducers, or system 'engineers', for much larger carbon, nutrient or water fluxes than their direct contributions to these fluxes (Anderson, 1995).

The roles of earthworms and termites in tropical agroecosystems are particularly important in this respect and are often manifested in the effects of treatments, such as mulching, on soil properties and processes. Unless the magnitude of soil fauna responses to treatments are recognized variation in plant responses may be difficult to interpret. Studies carried out in agroforestry systems in Sri Lanka (Bandara and Anderson unpublished) showed that mulches of green manure (*Gliricidia*) and rice straw resulted in much larger aggregations of earthworms than either resource on its own because the mixtures provided both a habitat and a high quality resource for the animals. As a consequence of their burrowing activities on soil structure, infiltration rates increased as a linear function of earthworm biomass with double the surface water fluxes under the mixtures than unmulched controls. Hence localized patterns of surface water runoff and infiltration can be manipulated using these fauna responses with consequences for both soil water storage and leaching of ions. Earthworms can also affect the timing and magnitude of nutrient release from organic manures as illustrated in Fig 4. Further details of the contribution of earthworms to tropical soil fertility are reviewed by Fragoso, *et al.* (1997).

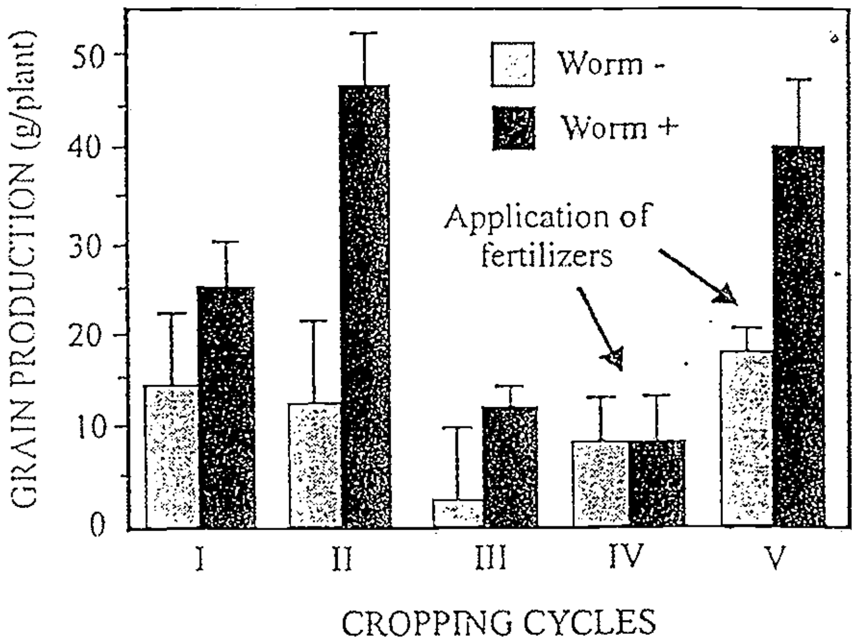


Figure 4. Effects of earthworm inoculation on grain production in a continuous maize crop in Peru (Fragoso, *et al.* 1997)

The effects of termites on agroecosystems are more complex than those of earthworms because some groups which have dominant effects on soils (many species of wood and litter-feeding Macrotermitinae) are also important economic pests of field crops in small-holder systems (Black and Okwakol, 1997). In many regions of the tropics, farmers have quite a detailed understanding of termite ecology, how crop damage can be limited by residue management and the benefits which they confer on soil fertility. Large termite mounds are often used as crop niches because of the higher nutrient status of the termite-worked soil and soil from old nests of *Macrotermes* and *Odontotermes*, which contain large repositories of nutrients from harvested plant materials, are used for soil improvement. Anderson and Wood (1984) showed that humus-feeding termites in Nigeria had dramatic effects on available P which increased by up to 400 times following gut transit. These termites were calculated to turnover about a third of the topsoil per year and were used by the local farmers as indicator of soil fertility restitution under forest fallows.

An important difference between the effects of termites and earthworms is in the extent to which termites modify soil structure, hydrologic processes and patterns of vegetation cover at the landscape scale. On any hillslope in the sub-humid and semi-arid tropics, management practices affecting the distribution of trees, grass cover, crops, and crop residue placement carried out by farmers will affect patterns of termite activities and the sources and sinks of surface water and suspended sediment.

In conclusion, small-holder farmers operate within a semi-natural environment where the the associated biodiversity can be important in maintaining functions above and below ground which affect crop production. Explicit recognition of these effects can be important because they can significantly influence the processes affected by management practices. For example, the effects of stover mulches on soil physical properties and crop growth can vary widely according to whether particular groups of termites or earthworms respond to the treatments. These biological processes are generally over-ridden in highly mechanised production systems.

Integrated nutrient management in multi-species, small-holder farms

The problems faced by smallholder farmers in the sustainable management of soil fertility are common to most farming systems in the tropics. But the solutions have to be considered specifically within the constraints imposed by the availability of labour, restricted land for fallows and limited amounts green manures, limited animal dung and inorganic fertiliser, or some combination of these factors. Many technical solutions developed in on-station research have not taken account of these resource constraints and adoption has been poor. On the other hand, the diversity of resources available to farmers, including their detailed indigenous knowledge of soil management, provides an opportunity to make small, but significant, incremental improvements in crop production by improving efficiencies of land use (*e.g.* by improved fallows) and organic matter/fertiliser management. The latter approach is considered here.

A key issue determining the efficiency of resource use is whether management is targeted at optimising the resources available to the crop within the cropping season or there is a carry over to subsequent cropping seasons which may result in the long term improvement of soil fertility. In general the latter strategy is reflected in much of the scientific literature on the use of crop residues in tropical soils management. In practice, however, the amount of plant material required to increase soil organic matter is often in excess of that available; particularly in seasonal climates where residual organic matter is rapidly decomposed at the start of the next rains when soil temperatures are high. An alternative approach is to establish the minimum amounts of organic matter and nutrients required to meet the requirements of the plant within the cropping season.

The phenology of a cereal, such maize, is shown in Figure 5 and illustrates the point that plants have specific requirements for water, nutrients and a favorable environment for root growth at different phases in the cropping cycle. The period when all of these requirements have to be optimized is shorter than the whole cropping cycle when different combinations of conditions need to be maintained. Hence resource use efficiency might be increased by techniques which improve the synchronization of soil water and nutrient availability with plant requirements through management of biogeochemical processes. The main management options available to the farmer are mulching, residue incorporation, selection of resource quality, crop variety and methods of applying mineral fertilisers.

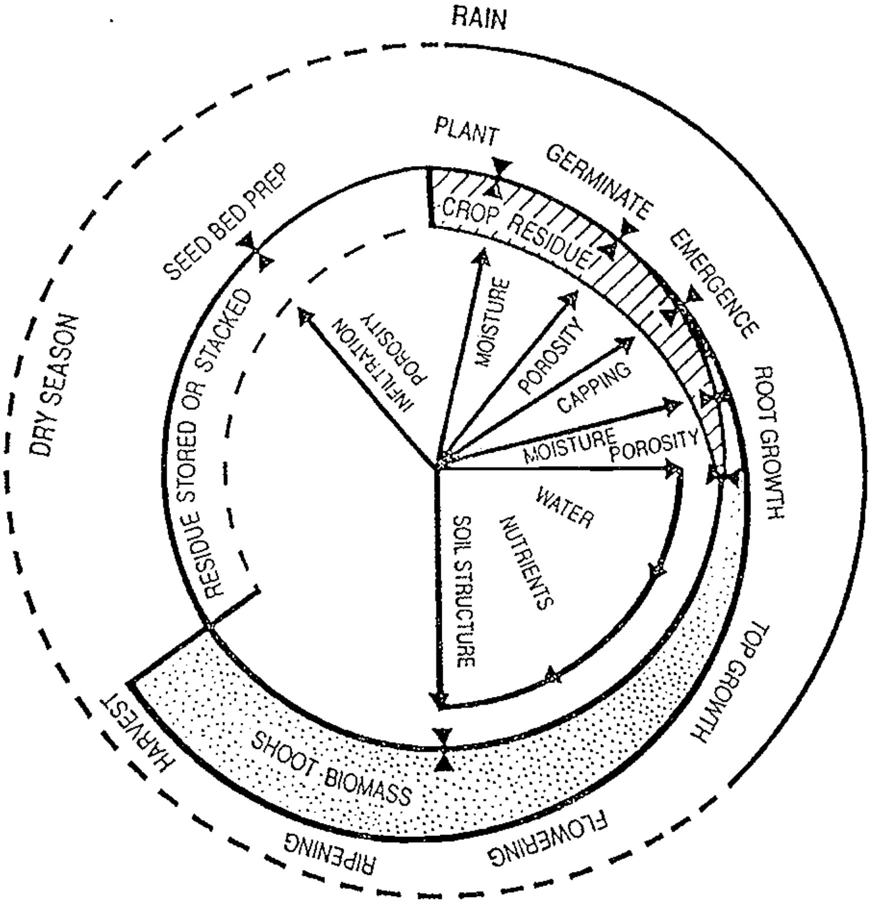


Figure 5. Representation of the growth cycle of a cereal crop, such as maize, and the biological processes (shown as gates) regulating critical soil conditions for plant root growth and nutrient uptake (Anderson 1995).

Mulching

The use of mulches to reduce soil erosion, elevate or reduce soil temperatures during periods of seed germination, and conserve moisture are widely practiced and extensively researched. Fewer studies have quantified the minimum amount and geometry of the mulches in relation to rain fall intensity and decomposition rates during the wet season to achieve these properties (e.g. Schomberg, *et al.,* 1996). Soils are vulnerable to erosion under slow growing crops, such as cassava which has an open canopy for the first 3-4 months after planting, but soil losses were three times lower under mixed cropping with maize or sweet potatoes (Aina, *et al.* 1979). Once the canopy closes any residual mulches have little effect on soil surface properties. Different mulch qualities and placement will affect soil fauna activities and surface water infiltration. Diversion of surface water runoff to sinks under mulches could enhance water capture and storage. In the humid tropics mulch decomposition takes place almost entirely on the soil surface and contributes little to soil organic matter formation even at local application rates far exceeding those relevant to farming systems (Haron, *et al.,* 1996; Ong, 1995; and Schomberg, *et al.,* 1996).

Residue incorporation

The incorporation of green manures and crop residues usually occurs during the preparation of the seedbed. The mass of resources and contact with the mineral soil has important implications for reducing active Fe and Al oxides (Bell and Bessho 1993), thus enhancing P availability by reducing P fixation and for soil organic matter stabilisation. Little research has been carried out on how the surface area:volume ratio of incorporated residues affects these processes. However, incorporating large residues, such as maize stover, is labour intensive and constrained by the type of hand implements or plough so that studies on residue placement should be defined within these constraints. Where organic matter is scarce, planting spaced crops in pits with dung or green manures, rather than broadcasting, increases the effective concentration of organic matter to improve localised soil properties (Al chelation/P fixation), improves the synlocation of nutrients and water for plant uptake by plant roots and increases the effective concentrations of plant available nutrients. Pit planting techniques, e.g. 'nine maize holes', are one of the many options farmers have developed for increasing effective resource concentrations (Table 3) but the soil processes underpinning crop responses have been little studied. Such technologies need to be developed through farmer participatory research to avoid building in unrealistic labour requirements.

Selection of organic matter for resource quality

The intrinsic rate of decomposition of organic materials is mainly determined by their chemical composition, or resource quality, which reflects their susceptibility to enzyme attack. The principal resource quality factors determining decomposition rates are the concentrations of nitrogen, lignin and polyphenol. Carbon: nitrogen ratios, or lignin: nitrogen ratios are important for predicting decomposition rates and N release from materials which have undergone natural senescence, whereas the polyphenol: N ratio or polyphenol+lignin:N ratio are more appropriate for green manures, particularly tree legumes (see Cadisch and Giller, 1997; Mafongoya, *et al.,* 1997)

The rates of mineral nutrient release from plant materials (including dung) is largely determined by the forms in which they occur in the cells and whether microbial mineralisation is required for their release. Consequently K losses are largely determined by physical processes influencing leaching, Ca mineralisation tends to track C mineralisation and mass losses closely, while mineralisation rates of N and P are closely geared to the availability of these elements to the microbial biomass (Heal, *et al.*, 1997). In the case of green legume manures there is increasing evidence that the concentration of protein-precipitating polyphenols influences the timing of N mineralisation, particularly where there is not strong leaching from the residues (Figure 6; Handayanto, *et al.*, 1997). Recovery of N from legume tree prunings estimated using ^{15}N-labelling has indicated that the N may be so tightly bound to polyphenols that little is released to three successive crops. Indeed recent experiments in which livestock were fed a large proportion of *Calliandra* prunings, which have a large content of polyphenols which actively bind to proteins, found that such a large proportion of the protein-N was so tightly bound into unavailable forms that the proportion of N released from the dung produced was much less than from other diets with comparable N contents (Delve, Cadisch, Thorne, Tanner and Giller, unpublished results). Few comparable studies have been carried out on P mineralisation and the effects on absorption isotherms of different types of organic matter inputs.

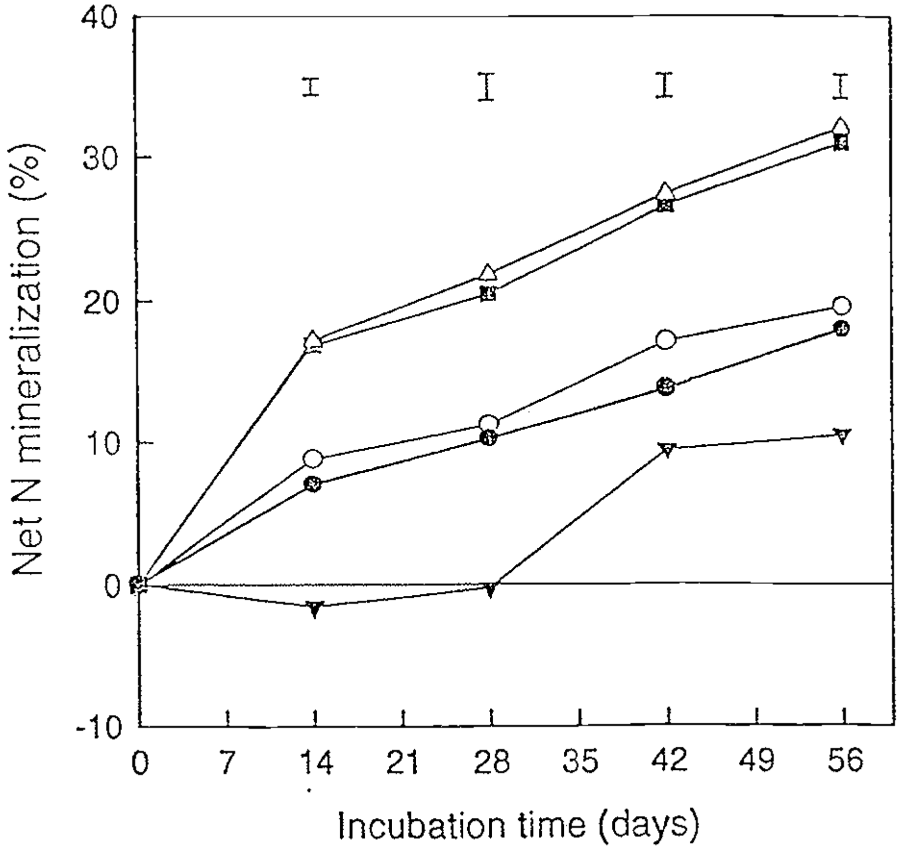


Figure 6. Net N mineralisation from mixtures of two tree legumes in relation to protein binding capacity of the polyphenols. Soils were incubated with different mixtures ranging from 100% *Gliricidia* (circles) to 100% *Peltophorum* (inverted triangles) under leaching (open symbols) and non-leaching (solid symbols) conditions (Handyanto, *et al.*, 1997).

The field rates of decomposition are modified by the climate and the soil environment for decomposition so that placement, mixing residues and the action of soil fauna all have major influences (Heal, *et al.*, 1997). For example, leaching of K is reduced by incorporating residues, and higher N or P availability from other plant materials or soil may enhance or 'prime' the decomposition of low quality materials. Also, earthworms can dramatically reduce the N mineralisation profile of high quality materials.

Farmers have very good practical understanding of how crop residues, dung and other organic resources can be used to best effect in traditional farming practices. However, shortage of organic matter necessitates both a more conservative approach to the utilization of these resources and/or the utilization of green manures with unfamiliar properties. Such technologies must therefore be developed with farmers to ensure that they have readily accessible criteria for resource quality assessment, rather than proximate analyses, and the performance of diverse organic manures under field conditions is predictable under variable conditions of climate, soil niches and management practices. The development of simple 'resource quality decision trees' such as that described by Swift (this volume) is a preliminary step towards this goal.

Crop varieties

Traditional land races of crops have been selected for water and nutrient use efficiency, cropping period, aluminium tolerance, pest resistance and many other characters which enable them to exploit niche conditions on the farm as well as storage, palatability and market values. The phenological characteristics and nutrient use-efficiencies of these varieties, and modern hybrids, have been extensively studies by breeders and agronomists and yet comparatively little information is available on the growth and development of the rooting systems; particularly in heterogeneous environments. Considerable on-station research has been directed at the root interface of agroforestry trees, legumes and improved cereal varieties since the seminal studies of van Noordwijk (1989) but there has been remarkably little research designed to exploit the potential differences in rooting systems between crop landraces in farm fields.

The development and architecture of crop rooting systems, such as those of maize, determines the uptake of water and nutrients (including leachates) in space and time. Does top dressing or superficial incorporation of nutrients promote extensive root development in topsoil which may result in drought stress and poor nutrient uptake compared to deeper placement? Such information is of critical importance in managing the synlocation and synchrony of these resources. Further studies are required on the genetic and adaptive characteristics of crop rooting systems in relation to resource use-efficiencies in the farm environment.

Management of mineral fertiliser

Integrated nutrient management requires firstly, understanding of what fertilisers are required to supplement plant nutrient deficiencies in organic manures and secondly, how the combined resources can be managed to maximise use-efficiencies of scarce resources.

There is increasing evidence that the most promising route to improving crop yields in smallholder farming systems is by increasing inorganic fertiliser efficiency through the addition of small amounts of high quality organic matter. Jones, *et al.*, (1997) review studies showing that the addition of *Leucaena* prunings in combination with mineral N and P fertilisers increased yields significantly in relation to each component in single treatments. In the absence of leaf prunings farmers were able obtain 17-25 kg maize for each kg N applied with good fertiliser management but up to 45 kg maize for each kilogram of applied nutrient in integrated treatments. Traore and Harris (1995) suggest that there are few, or no, benefits to framers of adding low quality residues to soils because they tend to immobilize N. In fact the situation is more complicated than this firstly because there are other benefits of mulching with crop residues (moisture conservation, erosion control, weed supression, etc.) and secondly because crop responses to integrated nutrient management (INM) can be quite variable. Figure 7 shows the estimated recovery of fertiliser N (50kg N ha^{-1} as calcium ammonium nitrate) with and without added stover (4 t ha^{-1}) at two sites in Kenya, over two growing seasons with different stover management practices (surface or incorporated). The interactions between the organic and inorganic inputs were modified by both macroenvironmental (between sites and seasons) and microenvironmental (with placement) effects. The organic-inorganic interactions show both decreases of N-availability as a consequence of immobilization (e.g. NARL, short rains, incorporated) and increases in mineralization (NDFRC, short rains, incorporated). The complexity of these responses emphasises the need for process studies carried out within farming systems to develop more predictive understanding of the benefits of INM with different qualities of resources, management practices and environmental conditions.

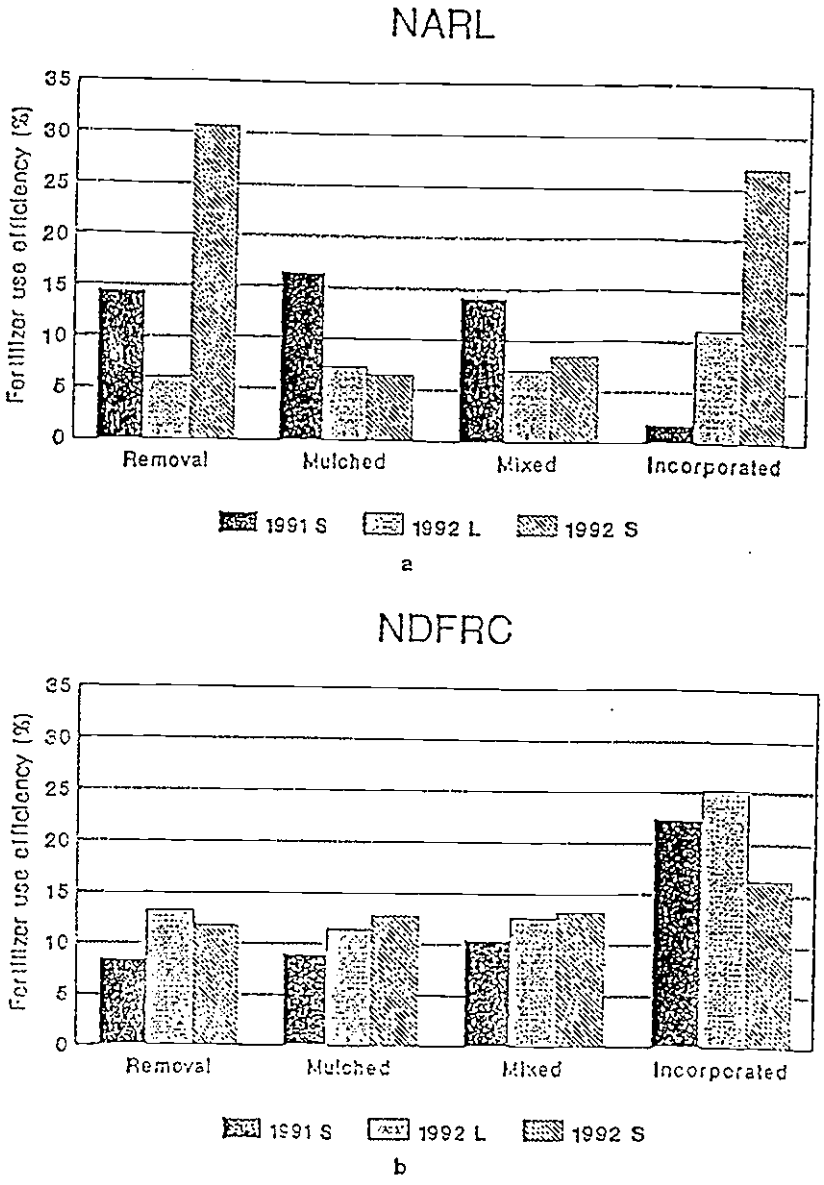


Figure 7. Fertiliser use efficiency (FUE) in maize cropping systems for three seasons at two sites in Kenya. FUE was calculated as (Grain-N for treatment - Grain-N in unfertilised control)/ N added in fertiliser). The National Agricultural Research Laboratory (NARL) has an annual rainfall of 923mm and is on a Nitisol; the National Dryland Farming Research Centre (NDFRC) has an annual rainfall of 673mm and is on a Luvisol. The seasonal rains are long (L) or short (S). (S. Nandwa and J.M. Anderson unpublished after Swift 1997).

Realising the agricultural potential of soils though organic farming in these systems is often limited by the mass and quality of organic matter available on farm and by understanding of its plant nutrient composition. The recent development of the Organic Resource Database System (ORDS) is a useful tool to draw together the wealth of information already available on nutrient contents in a wide variety of organic resources, and to indicate the likely availability of nutrients to crops. To provide adequate supplies of a limiting nutrient in low concentrations using organic manures inevitably requires the addition other elements in excess. Even where N availability is enhanced through N_2-fixing legumes, attempting to optimise crop requirements for K or P can result in inefficient use of scarce organic resources. Consequently, limited amounts of low quality organic manures can result in nutrient deficiencies in crops because of the absolute and relative concentrations of elements, immobilization of exogenous N and P, and patterns of nutrient release which are asynchronous with plant demand. Fresh plant materials and crop residues have fairly predictable nutrient concentrations but composts and dung can be extremely variable in N, P and K contents; though farmers usually have simple pragmatic criteria for defining the quality of organic manures. Enabling the farmers to carry out small inorganic fertiliser response trials can also provide them with insight into nutrient deficiencies in soil niches with and without organic amendments.

Developing management practices to maximise the use-efficiency of organic and mineral fertilisers depends on determining whether there are supplementary or synergistic effects of combining the resources. In the former case, the additions of organic matter improve the physical and chemical environment of soil for root growth and fertilisers are used to correct and enhance plant nutrient requirements. In the case of N and P the interactions between the organic and mineral resources are more complex and may involve the immobilization and delayed release of N by low quality resources, such as maize stover, and the dynamics of P fixation in relation to organic matter complexing of Fe and Al oxides. The mechanisms of the processes are generally well understood but not in the context of timing and placement of these resources in small-holder farms where organic resources may be limited. In addition, the use of plant materials with high tannin and polyphenol concentrations introduces a chemical dimension to the dynamics of N and P interactions in soils which have been little studied in agroecosystems. An additional complication is added by the regulating role of the soil itself on decomposition processes. Decomposition is so rapid in sandy soils that there is little scope for regulating nutrient release through modifying the decomposition process by for example, varying resource quality. In soils with a larger clay content there is much greater scope for modifying rates of nutrient release by using resources of different quality.

Conclusions

Multispecies farming systems provide a challenging context for integrated nutrient management because of the diversity of organic resources available to farmers on one hand, and on the other the limited options for management constrained by low amounts of different organic resources, limited availability of mineral fertiliser, and labour constraints. (Table 4). Farmer participatory research should be developed to:

- learn how farmers manage their resources and the bases on which they decide whether to use plant biomass for animal feed, mulch or soil nutrient amendment,
- characterise labour, organic resources, fertilizer availability and resource management practices,
- work together with farmers to enable more sensitive assessment of nutrient limitations in soil niches,
- determine threshold levels of plant biomass and residues needed to maintain biophysical conditions supporting crop growth above and below ground,
- develop farmers' appreciation of quality assessment criteria for organic resources and balancing deficiencies with inorganic fertiliser,
- research into the placement and interactions of inorganic fertiliser (particularly rock phosphate and TSP) and different types of organic matter (crop residues, dung and green biomass) to increase nutrient use efficiency of food crops,
- assess the root architecture of crop land races, particularly maize, so that resource placement can improve water and nutrient availability,
- promote the value of conserving and managing the associated biodiversity in agroecosystems to maintain functions and services which otherwise have economic costs for replacement.

Table 4. Management options for organic resources

Management option	Drawback/constraint
Quality	
Choice of species	
• In situ production (green manure/crop residues)	Trade-off in economic value vs crop and other uses
• Extensive harvesting	Labour, value of product use
Management	
• Mixing of resources	Labour
Placement	
• Surface, incorporated, trenched, etc.	Labour Erosion risks Leaching/volatilisation
Timing	
• Adjusting crop species to nutrient availability	Reduced choice of varieties
• Selection of organic resources and inorganic fertiliser	Availability and knowledge Predictability of responses
• Combination of organic matter	Availability and knowledge
Plant roots	
• Inherent and adaptive responses of plant roots to soil environment	Knowledge and predictability

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Working group on forest agriculture interface production system

Chairman: Prof. Ken Giller
Rapporteur: Barry Pound
Keynote Paper: Prof Jo Anderson

1. **Definition of the forest/agriculture interface**:
   Area with on farm or off-farm forest resource; situations where harvestable biomass is a small proportion of the total. Need to distinguish between traditional forest users (e.g. Nepal), and newly settled areas (e.g. S. America).

2. **Characteristics of forest/agriculture interface**:
   - Bio-diversity. Need to value forest components, including soil organisms compared to cleared land.
   - Importance of livestock in system; potential for zero grazing
   - Socio-economic factors influencing decisions about investment in soil fertility maintenance (e.g. gender, tenure, access to forest resources)
   - Tree/crop competition or complementarity; open to manipulation
   - Choice of organic matter management options; how to use optimally (temporal, spatial, quality, quantity, mixtures); what are the constraints?
   - Agricultural practices leading to reducing soil organic matter (e.g. slash and burn). What are the critical concentrations to maintain SOM functions and how can these be sustained?
   - Wide variation in organic matter quality. How to predict this, and its effects in different situations?
   - Rapidly changing nutrient budgets in dynamic F/A I situations (e.g. pioneer to agriculturist to grazier). How to measure/mitigate these?
   - Reducing use of bush fallows; how to manage/improve fallows? potential for multiple use/multiple species fallows.

3. **Recommended approaches to research**
   - Multidisciplinary, systems approach
   - Inter-institutional with networking and collaboration North-North and North-South (NARS/NGOs/CBOs)
   - Use of "flagship" sites and ensure links to NGOs and farmers to encourage synergy
   - Process approach, due to dynamic, poorly understood situations
   - Include policy issues in project design, planning and outputs
   - Concentrate research efforts ON-FARM
   - Identify farmer priorities/constraints from outset
   - Characterise system, including its historical perspective
   - Use PhD students as cost effective option
   - Research outputs disseminated in such a way that they are niche-specific

Suggested research topics: forest/agriculture interface

TOPIC 1

Researchable constraint

Limited cropping period due (in part) to reduction in soil fertility after forest clearance

Priority issues

Limited availability of Phosphorus to plants (pH, buffering)
Aluminium toxicity
Root competition/complementarity
Unsustainable organic matter management, including burning

Suggested project

Develop appropriate cropping patterns and organic residue management methods to maximise the availability and utilisation of nutrients to enable sustainable and productive cropping.

TOPIC 2

Researchable constraint

Reducing SOM levels after forest clearance

Priority issues

Limited understanding of the functions of Soil Organic Matter
Unsustainable agricultural practices at the forest margin leading to forest degradation

Suggested project

Determine the critical concentrations of soil organic matter fractions to maintain the various SOM functions, leading to recommendations for organic residue management

TOPIC 3

Researchable constraint

Poor uptake of outputs from soil research

Priority issues

Understanding of land user's decision making processes
Interfacing knowledge between farmers and scientists

Suggested project

Through an understanding of farmer's needs for soil-use information, develop methods of making research results available and accessible to farmers in such a way that they can be applied to niche-specific situations.

Note: It was suggested by the group that research could be directed towards two distinct systems: A. The forest margin, where the emphasis is on the flows of nutrients from forest biomass to cropped land; B. The fallow system, where the emphasis is on diversity and complementarity of species/use.